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Energy Flow in neutrino events in ND-GAr:  
Using ParamSim “caf” trees

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# Motivation

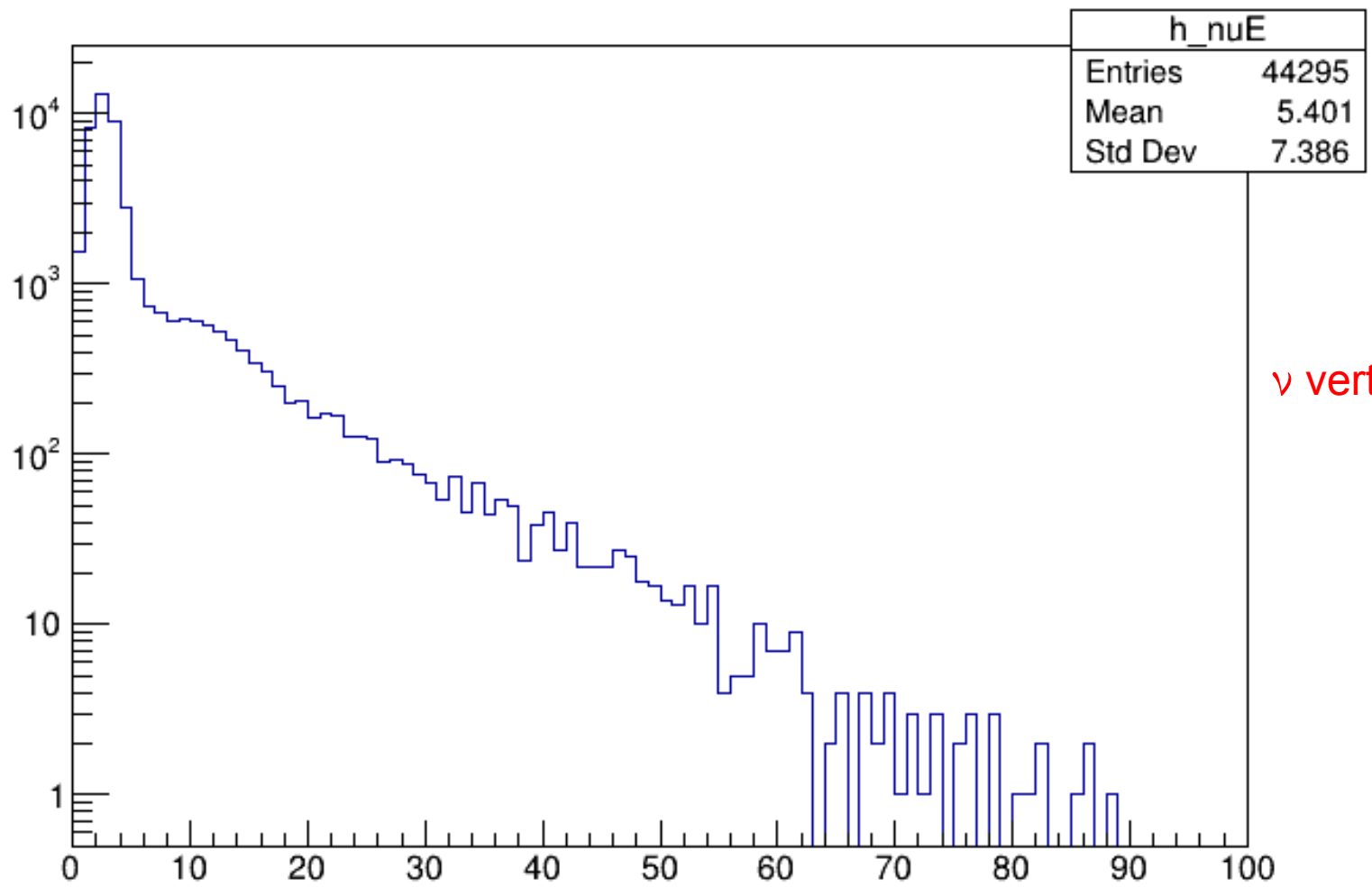
- Looking at location of energy deposits in the ECAL
  - Use both Truth and Reco variables (latter based on ParamSim)
- I am looking at “caf ” trees made by Eldwan/Tanaz, using ParamSim
  - Events are generated in ND-GAr
  - Center of coordinate system is ( $\sim 0$ ,  $-150.47$ ,  $1486$ ) cm. Make cuts relative to this
  - Very nice documentation on github (<https://github.com/ebrianne/ParamSim?organization=ebrianne&organization=ebrianne>)
- Not doing anything sophisticated here
  - Only use particles that are produced in the primary neutrino interaction.
    - If we have a primary  $\pi^0$ , use energy of its daughter photons, and ignore the  $\pi^0$
    - A small fraction of the time, almost always in DIS events, we get primary strange hadrons – for now, pretend that they are fully detected, regardless of their decay mode:
      - This is done only for truth level information.
      - When using reco information, these particles are included only if they manage to get to the CALO, e.g.,  $K_L$ , while  $K_S$  and  $\Lambda$  are likely to be ignored since their lifetimes are shorter.
    - Ignore outgoing neutrinos (in NC events), since they are always undetected
    - Charged particles going through the CALO leave behind  $\sim 49$  MeV of energy

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# Reco variables

- Variables like preco, recopid are working
  - We need to fix some parameters in Gluckstern formula, but that doesn't affect this talk
- Worked with Eldwan on ECAL based variables, e.g., erecon
  - At the moment, we are using KE for all particles – this needs to be fixed so that we use KE only for nucleons, and total E for all others
  - CAF trees contain flags to tell us where the particle stops, e.g., in TPC, CALO, or if it goes through the CALO, etc.
    - Also, tells us if particle is in barrel or endcap
- Aggregated over all neutrino flavors, event types (QE, RES...), particle momenta

nuE

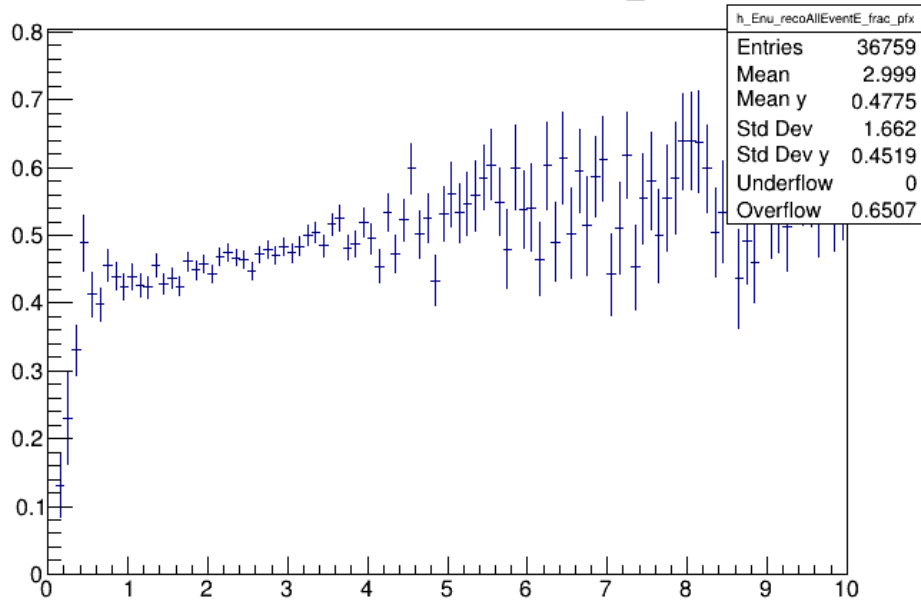


$\nu$  vertex in TPC fid. vol

3.5% with  $E < 1$  GeV, 48% with  $1 \leq E < 3$  GeV, 26% with  $3 \leq E < 5$  GeV and 22% with  $E \geq 5$  GeV  
(0.4% with  $E > 50$  GeV)

# How much of the incident neutrino E is reconstructed?

frac of AllrecoE in event vs. E\_nu



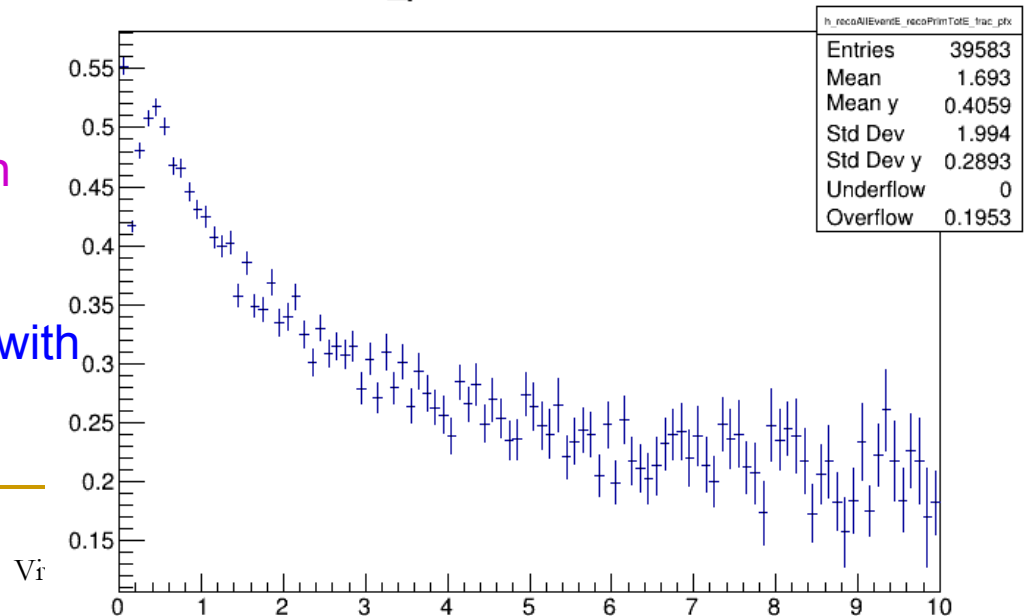
<Fraction> of incident neutrino E that is reconstructed in CALO vs  $E_{\nu}$  – here I just loop over all particles in event, with  $\text{reco}_E > 0$

<Fraction> of all reco E in event that shows up in primary particles that reach the CALO

In the ensuing plots, I am only working with reco. energy of primary particles

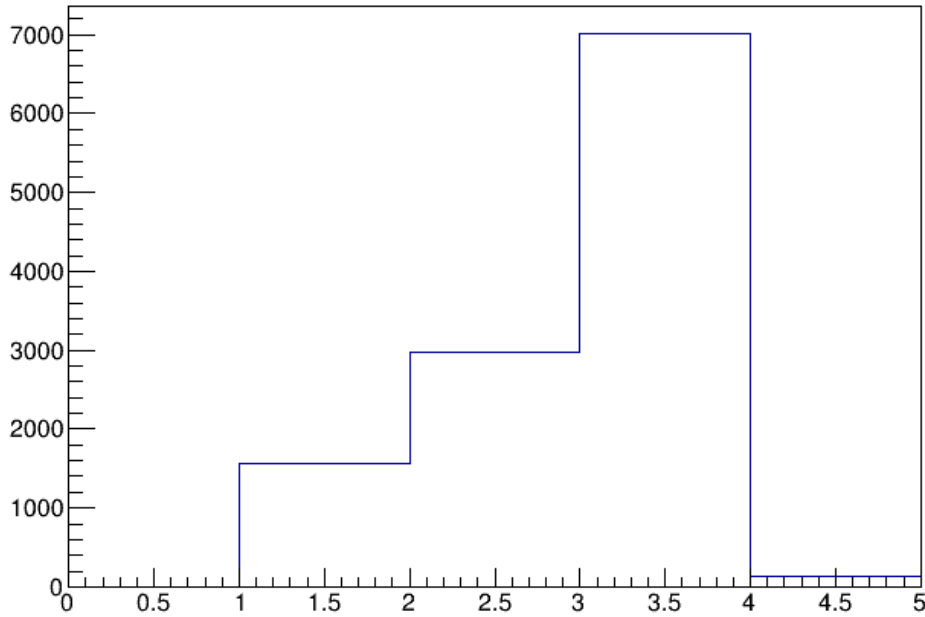
Maybe I should be using all particles in event that make it to the CALO??

frac of recoE primaries vs. AllrecoE in event

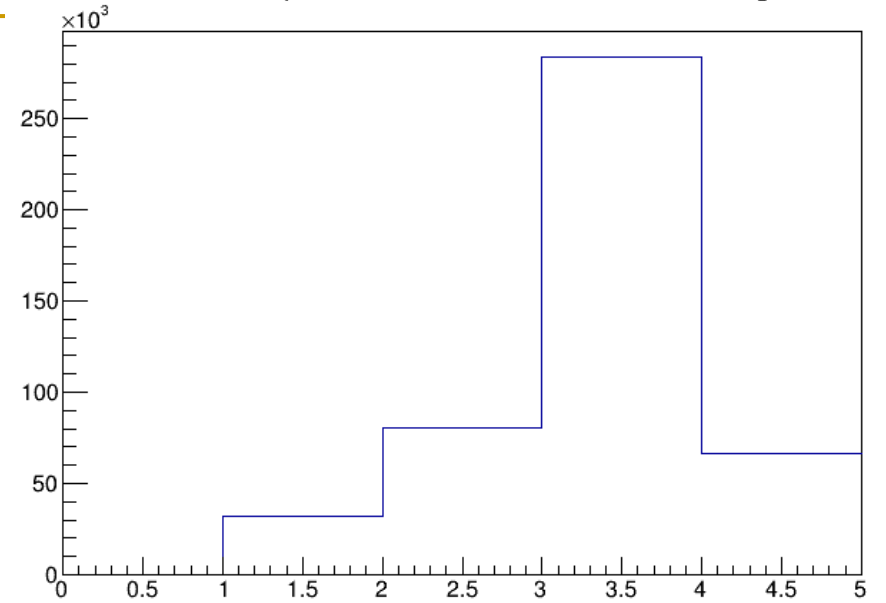


$V_i$

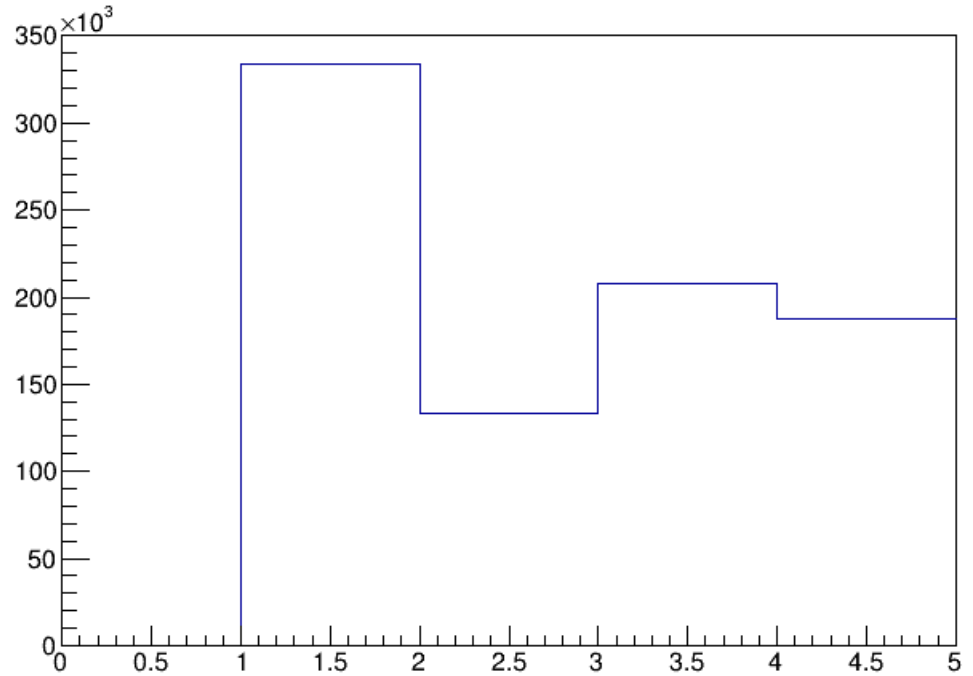
gamma stop: 1:TPC, 2:Between, 3:CALO, 4:Through



neutron stop: 1:TPC, 2:Between, 3:CALO, 4:Through



All except n,gamma - stop: 1:TPC, 2:Between, 3:CALO, 4:Through



Where do various particles stop?



# Two separate studies

- Look at energy deposits in annular rings, where *angle is measured relative to the direction of the incoming neutrino*

- Ring sizes chosen to have similar statistics
- Look at E due to all particles, and also just neutrons/photons
- For this check, I am aggregating over endcap and barrel

ring\_0 :  $\cos\theta \geq -1$  &  $\cos\theta < -0.5$  (very backward)

ring\_1 :  $\cos\theta \geq -0.5$  &  $\cos\theta < 0$

ring\_2 :  $\cos\theta \geq 0$  &  $\cos\theta < 0.26$  (forward hemisphere)

ring\_3 :  $\cos\theta \geq 0.26$  &  $\cos\theta < 0.5$

ring\_4 :  $\cos\theta \geq 0.5$  &  $\cos\theta < 0.68$

ring\_5 :  $\cos\theta \geq 0.68$  &  $\cos\theta < 0.82$

ring\_6 :  $\cos\theta \geq 0.82$  &  $\cos\theta < 0.92$

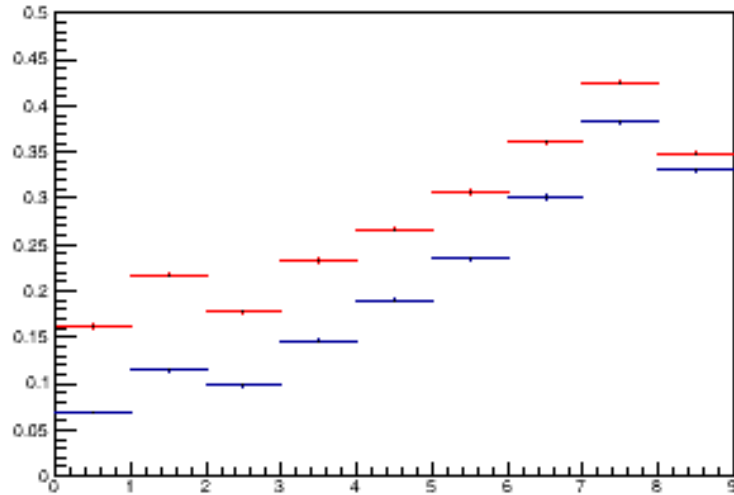
ring\_7 :  $\cos\theta \geq 0.92$  &  $\cos\theta < 0.98$

ring\_8 :  $\cos\theta \geq 0.98$  &  $\cos\theta \leq 1$ . (very forward)

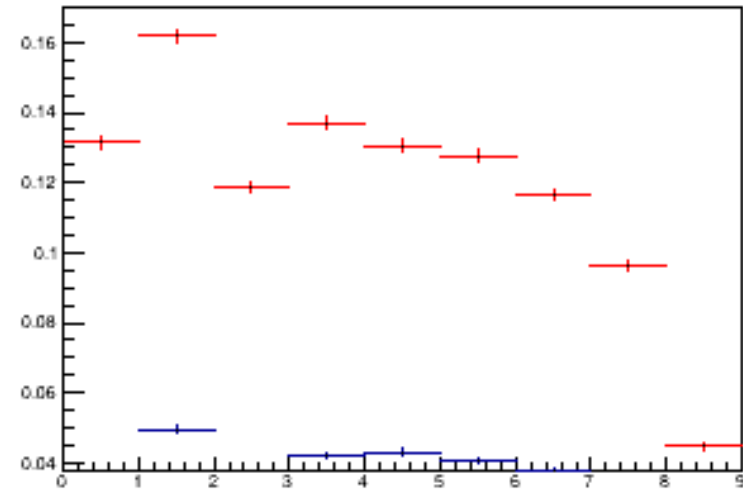
- Also have variables that tell us if a particle is in the barrel/endcap region
  - Combine with flags to see if it ends in the CALO or goes through it.
  - **This is done as a separate check**

These plots give the fraction of times there is non-zero energy in a ring - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample = 44295) Energy in one event can be spread over different rings

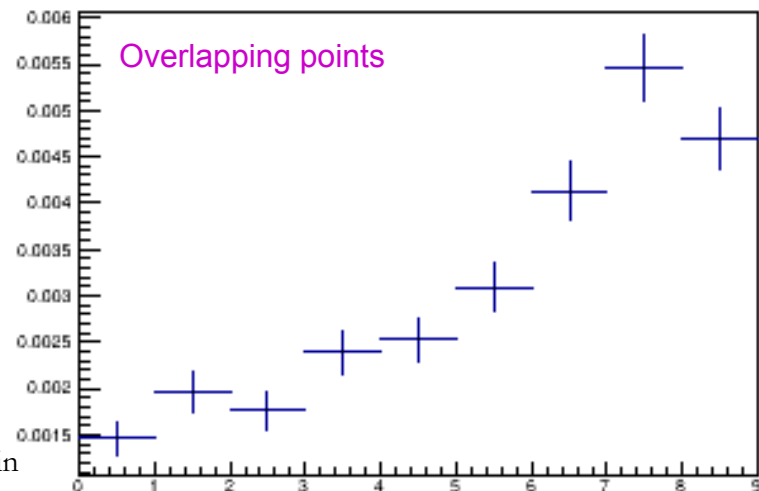
num of cases with Etot = 0 or >0



num of cases with Etot\_neutron = 0 or >0



num of cases with Etot\_gamma = 0 or >0



Truth, Reco

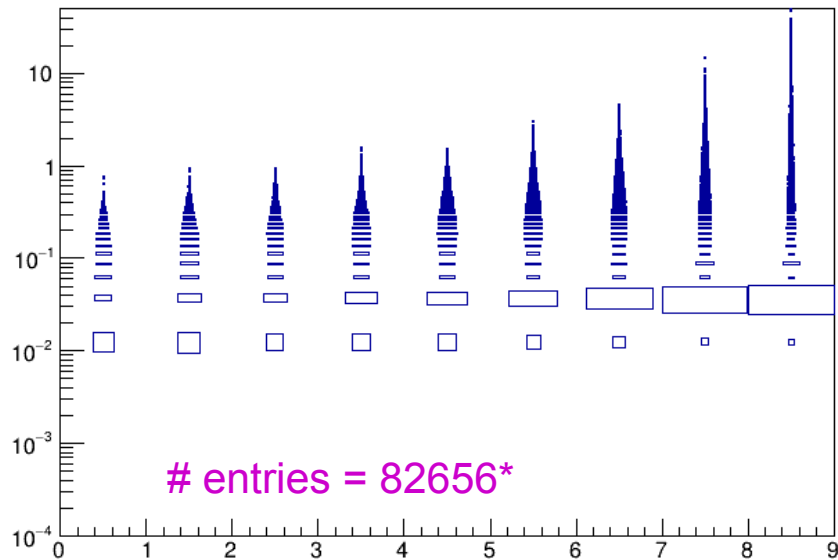
If a reco. point does not show up, it means it's below the plot's min Y



These plots give the amount of non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

### Reco information

reco total energy in annular rings



Y-bin width = 25 MeV

1<sup>st</sup> Y-bin is not being plotted?

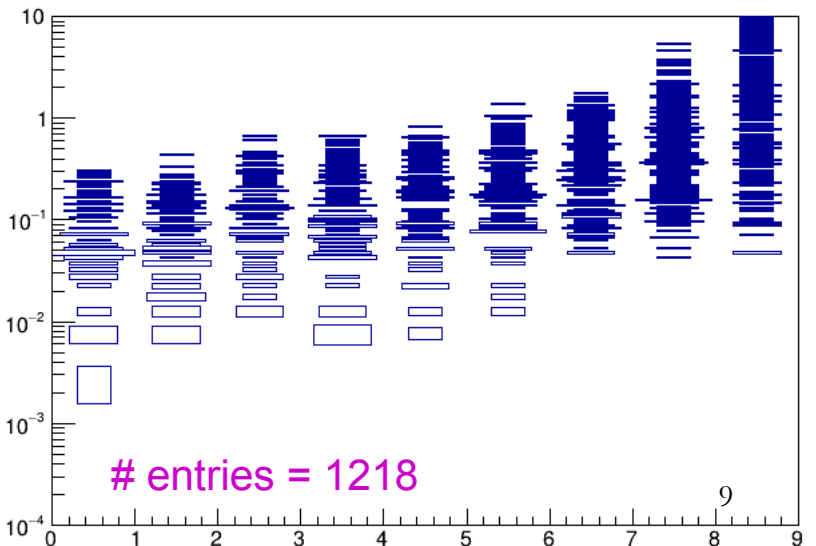
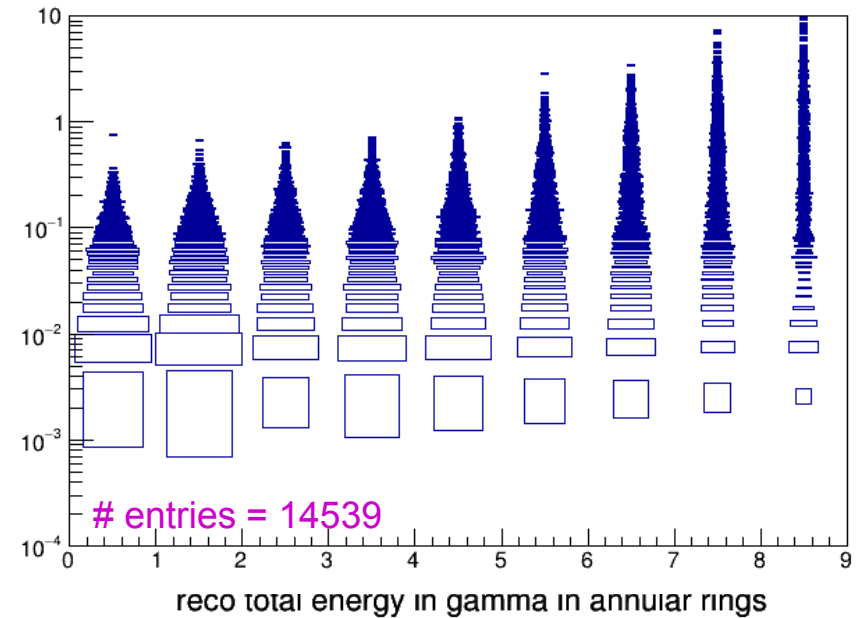
### Note:

Each plot has different number of entries, and  
Each bin has a different number of entries

Y-bin width = 5 MeV

\* out of 82656 entries, 32643 are from muons

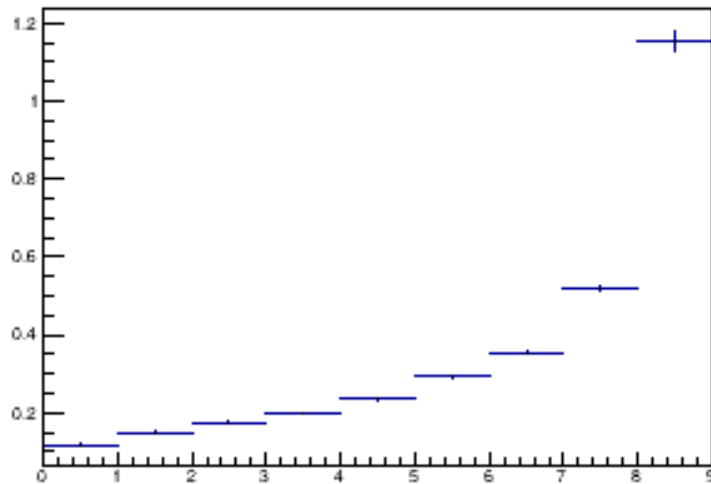
reco total energy in neutrons in annular rings  
Y-bin width = 5 MeV



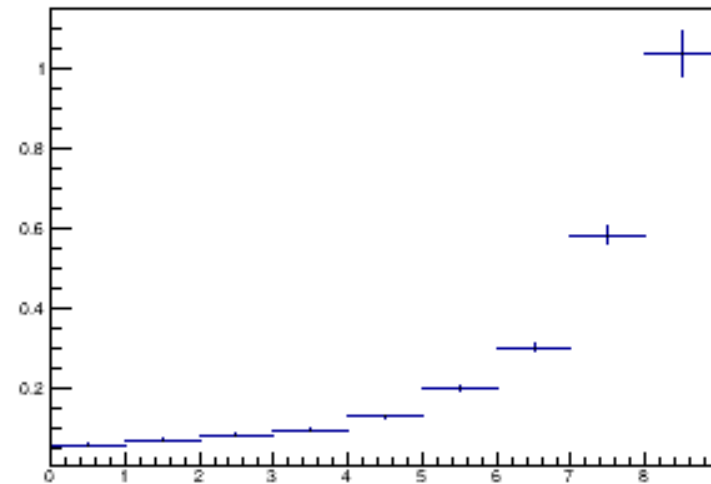
Profile plots give the amount of average non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

## Reco information

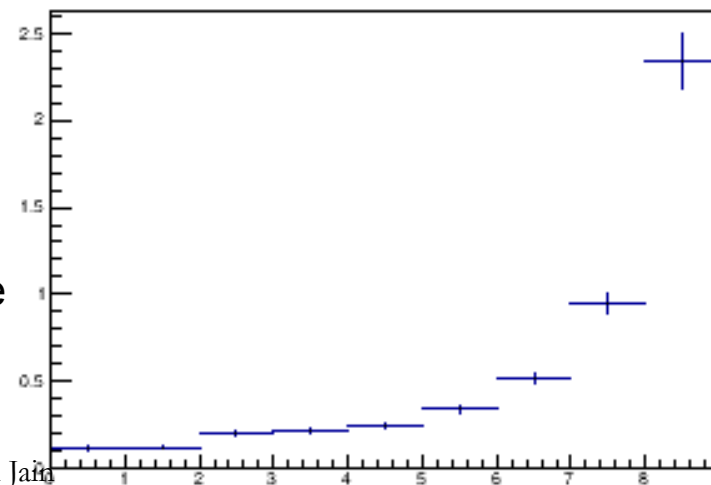
reco total energy in annular rings



reco total energy in neutrons in annular rings



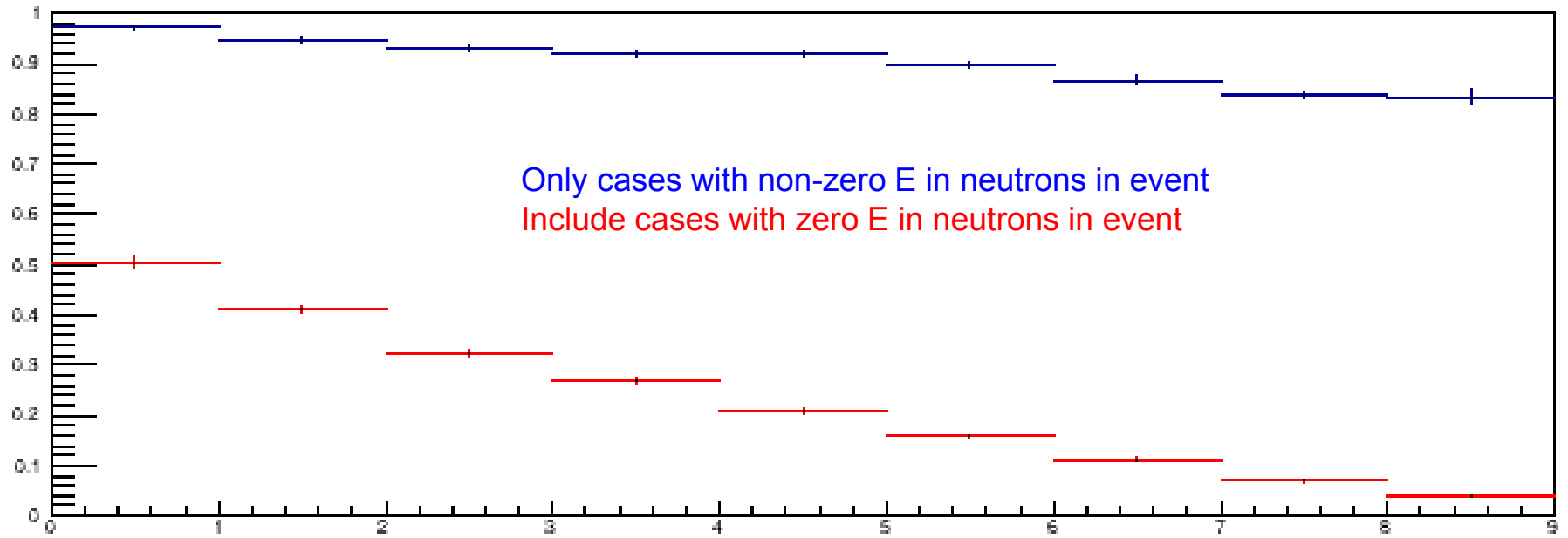
reco total energy in gamma in annular rings



### Note:

Since each plot has different number of entries, and each bin also has different number of entries, the sum of the parts can be greater than the whole

frac E in neutrons in annular rings - only evts w/ non-zero E in neutrons



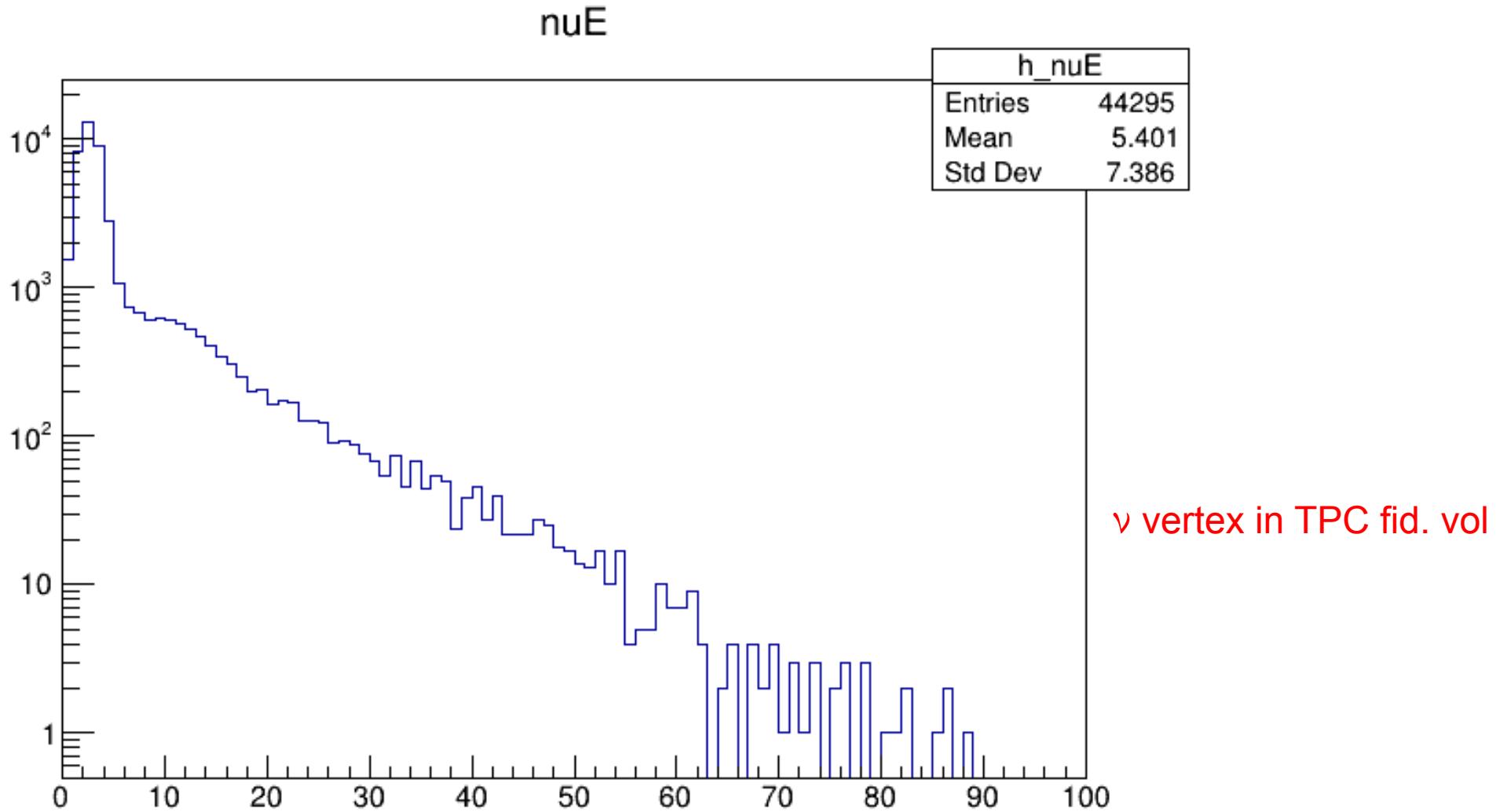
Only cases with non-zero E in neutrons in event  
Include cases with zero E in neutrons in event

frac E in gamma in annular rings - only evts w/ non-zero E in gamma



Only cases with non-zero E in gamma in event  
Include cases with zero E in gamma in event

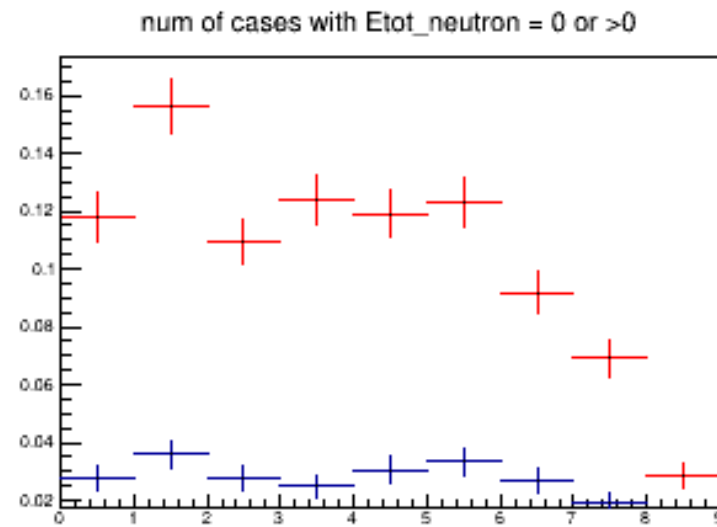
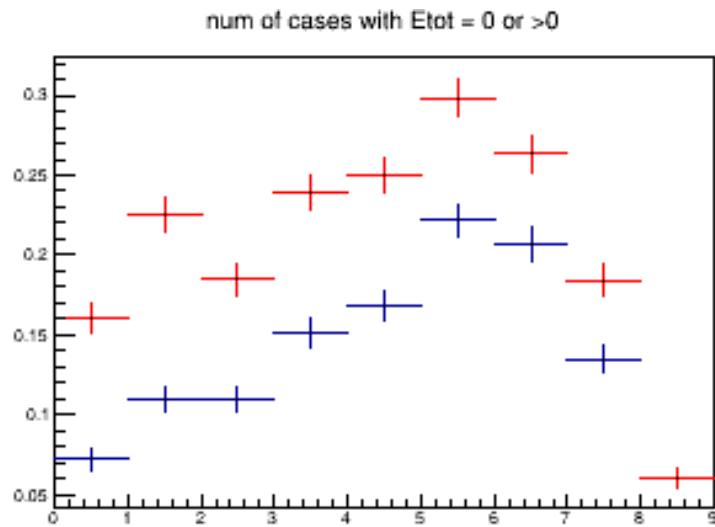
# Look at distributions in bins of incident neutrino energy



#: 1535 with  $E < 1$  GeV, 21364 w/  $1 \leq E < 3$  GeV, 11664 w/  $3 \leq E < 5$  GeV and 9732 w/  $E \geq 5$  GeV

(0.4% with  $E > 50$  GeV)

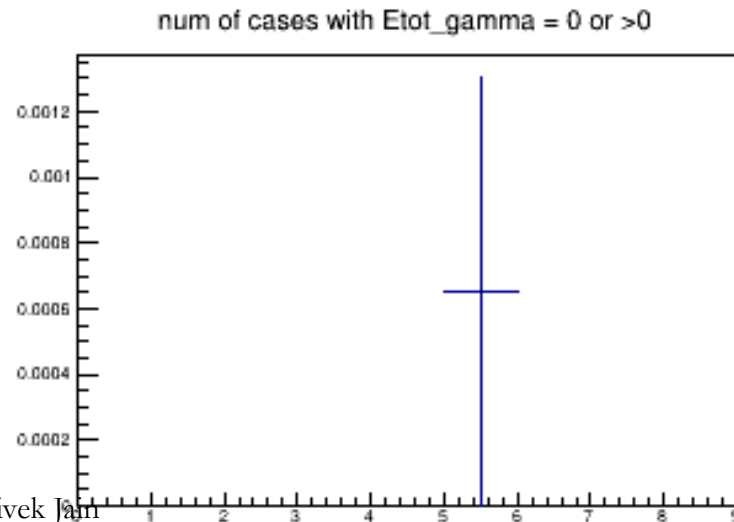
These plots give the fraction of times there is non-zero energy in a ring - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample = 1535 ) Energy in one event can be spread over different rings



Truth, Reco

Incident neutrino  $E < 1$  GeV

If a reco. point does not show up, it means it below the plot's min Y

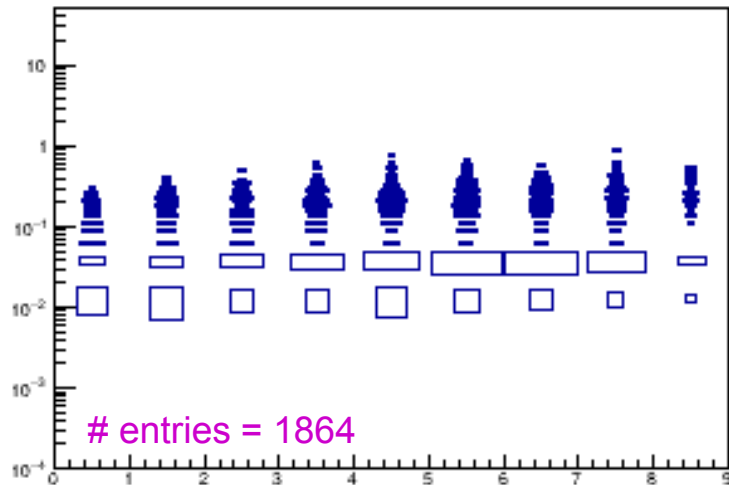


These plots give the amount of non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

Incident neutrino  $E < 1$  GeV – using reco information

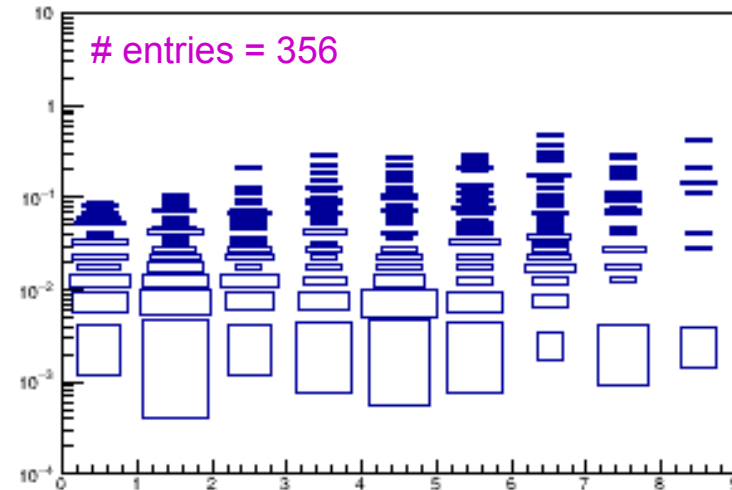
Y-bin width = 5 MeV

reco total energy in annular rings

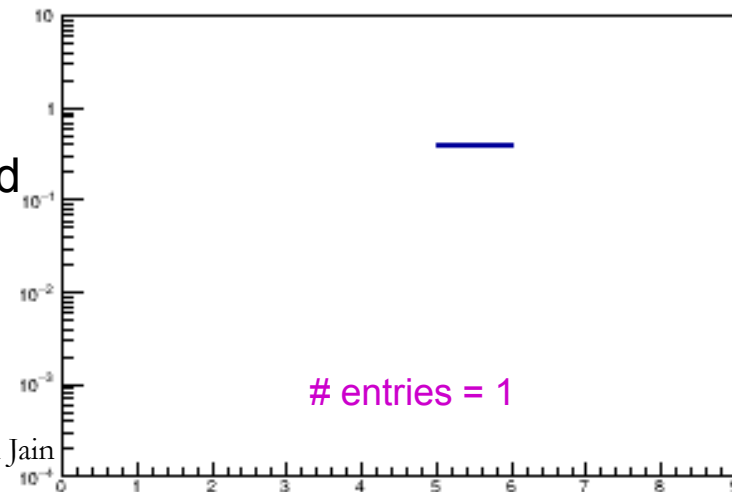


Y-bin width = 25 MeV

reco total energy in neutrons in annular rings



reco total energy in gamma in annular rings

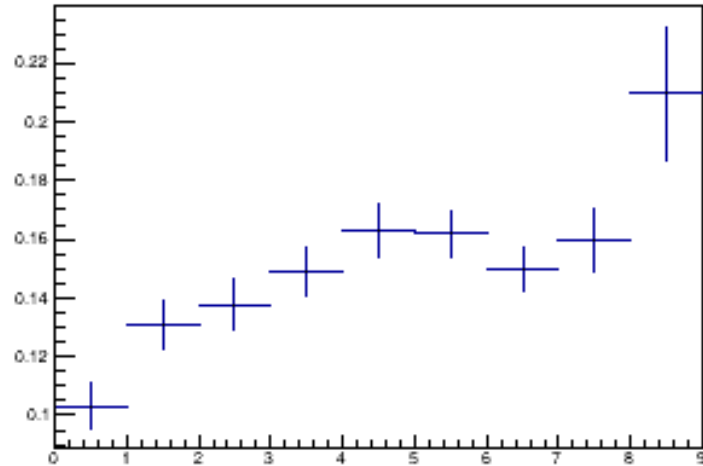


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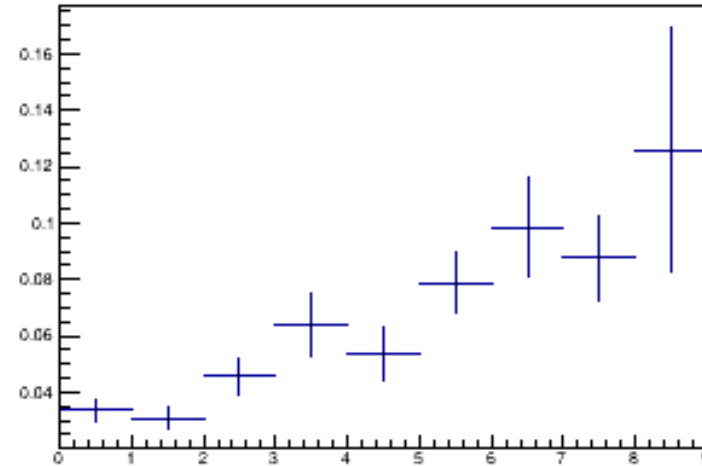
Profile plots give the amount of average non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

### Incident neutrino $E < 1$ GeV - using reco information

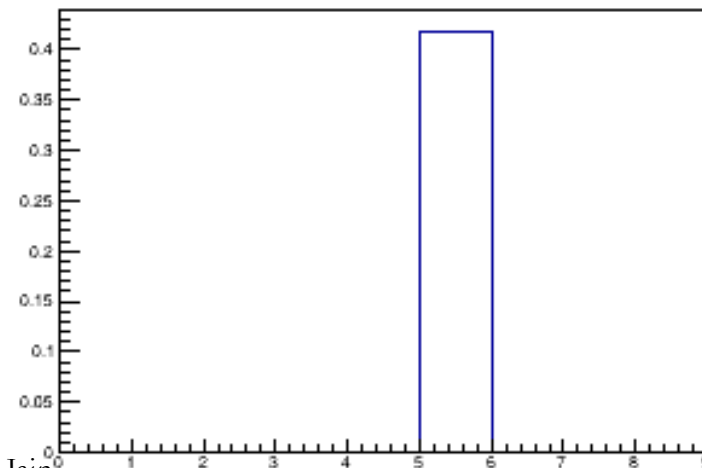
reco total energy in annular rings



reco total energy in neutrons in annular rings



reco total energy in gamma in annular rings

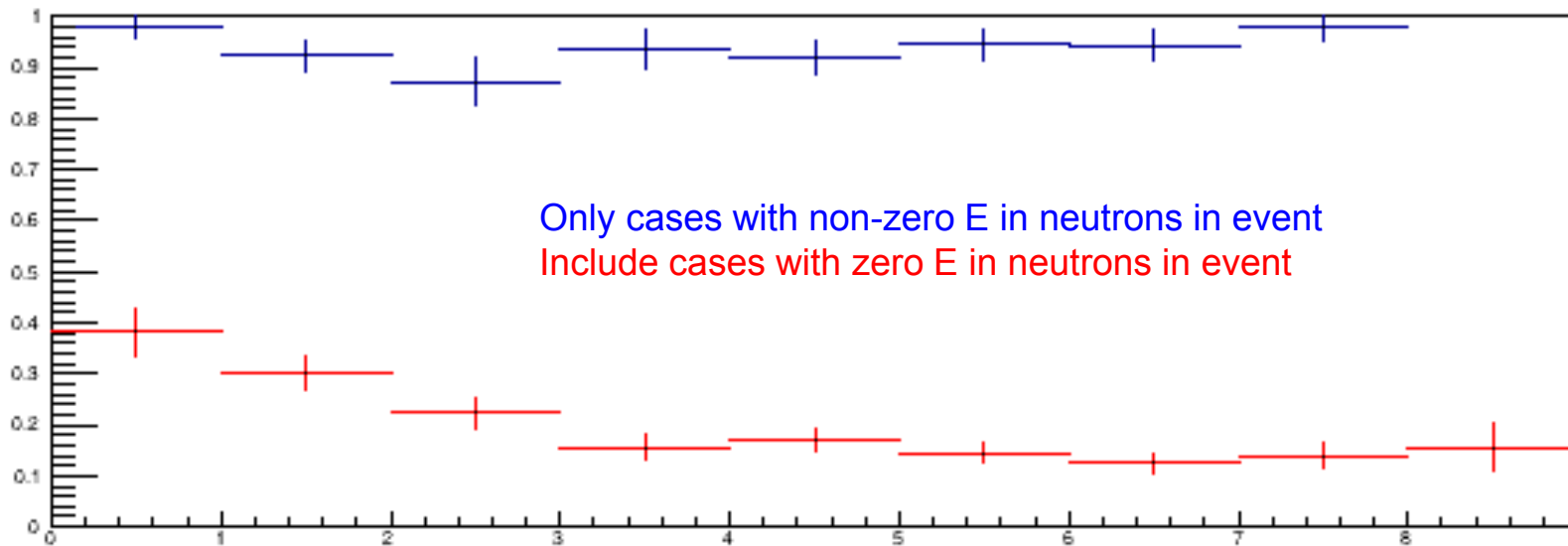


**Note:**

Since each plot has different number of entries, and each bin also has different number of entries, the sum of the parts can be greater than the whole

$E_\nu < 1 \text{ GeV}$

frac E in neutrons in annular rings - only evts w/ non-zero E in neutrons

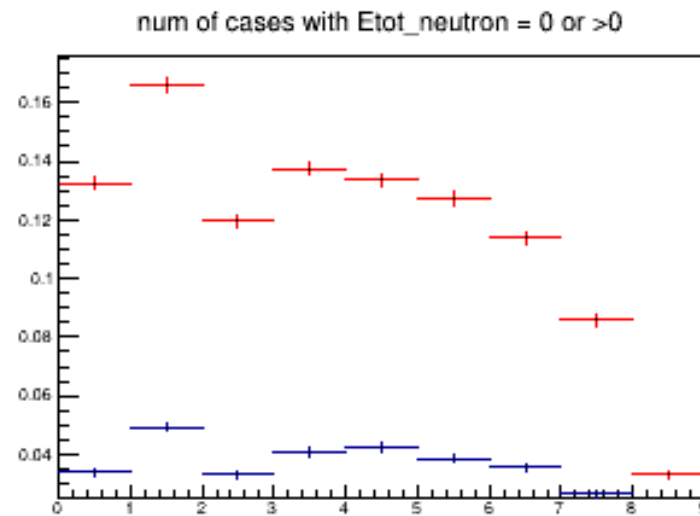
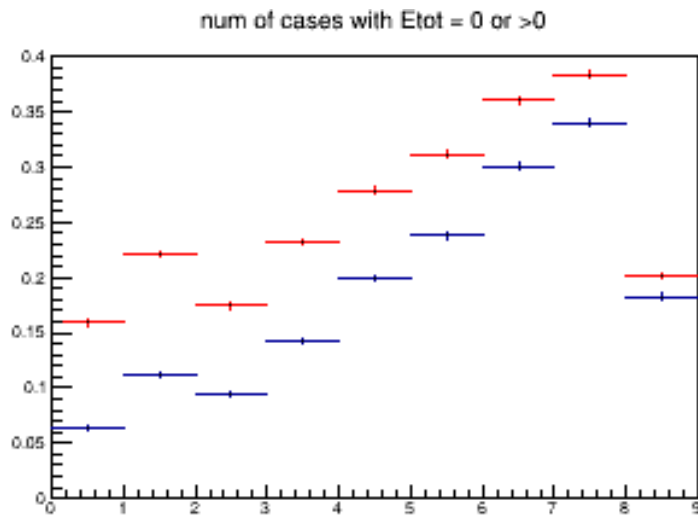


frac E in gamma in annular rings - only evts w/ non-zero E in gamma





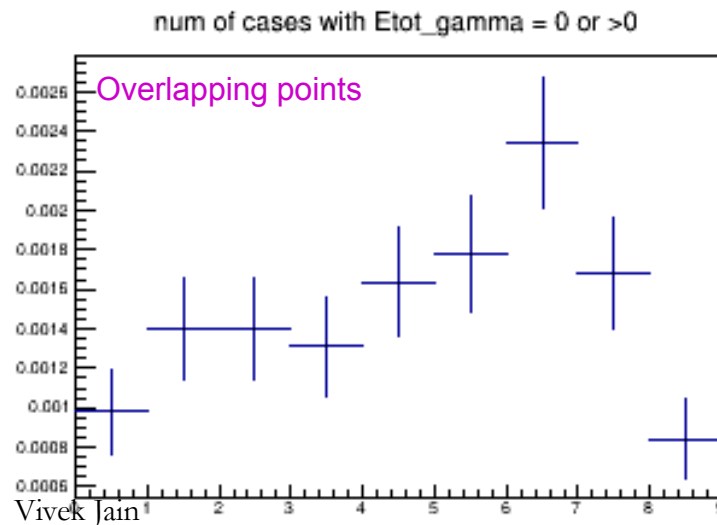
These plots give the fraction of times there is non-zero energy in a ring - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample = 21364 ) Energy in one event can be spread over different rings



Truth, Reco

Incident neutrino E: 1-3 GeV

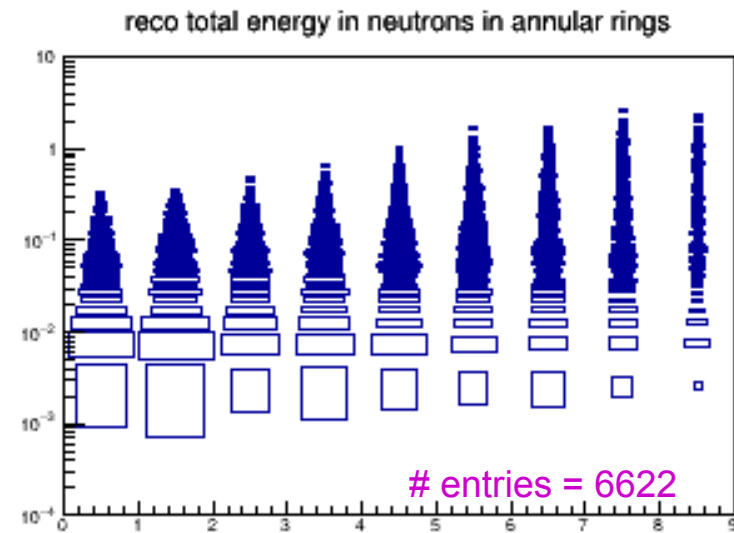
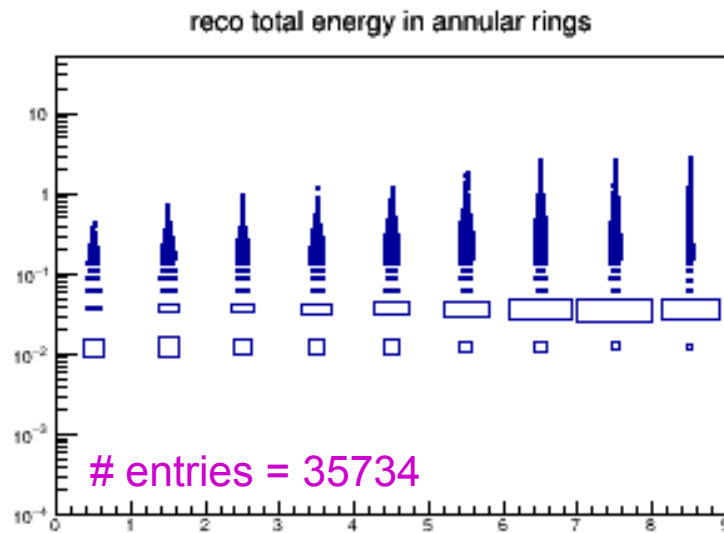
If a reco. point does not show up, it means it's below the plot's min Y



These plots give the amount of non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

Y-bin width = 5 MeV

### Incident neutrino E: 1-3 GeV – using reco information

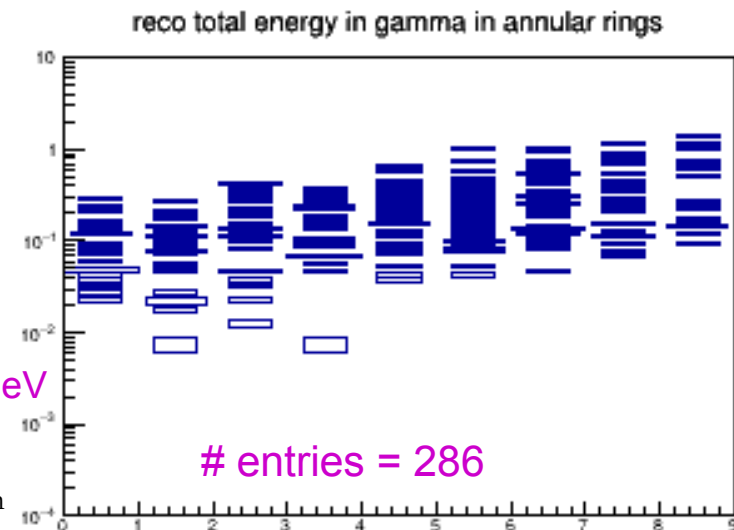


Y-bin width = 25 MeV

**Note:**

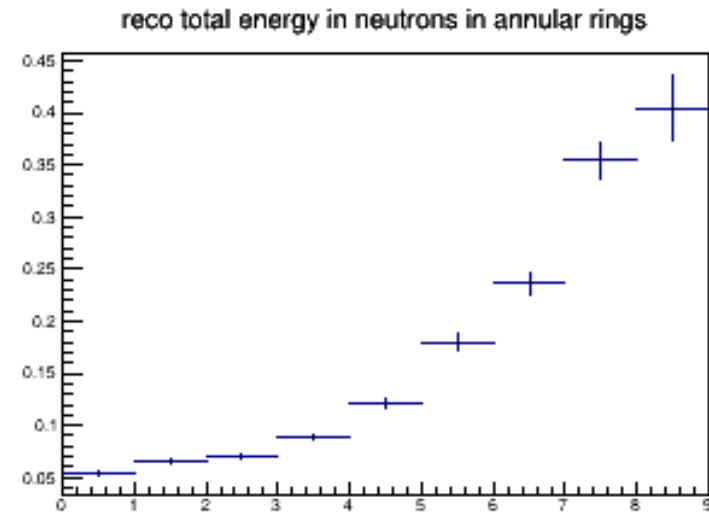
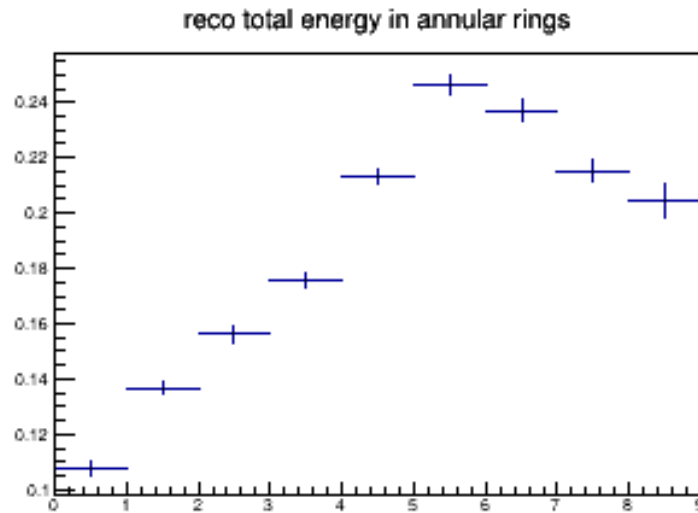
Each plot has different number of entries, and Each bin has a different number of entries

Y-bin width = 5 MeV



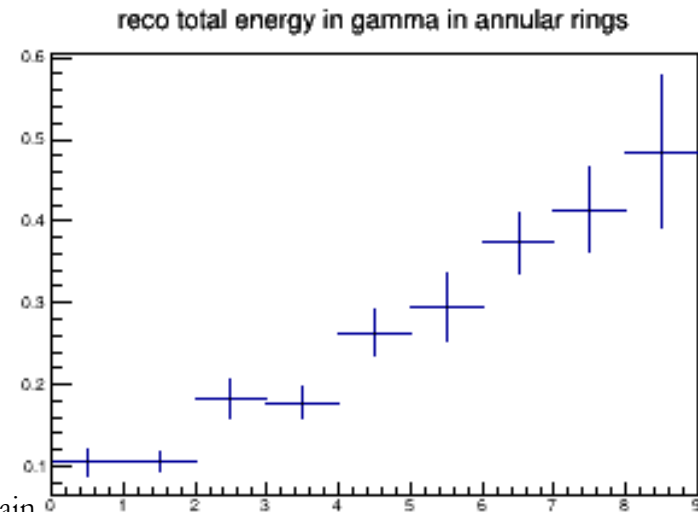
Profile plots give the amount of average non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

### Incident neutrino E: 1 - 3 GeV - using reco information



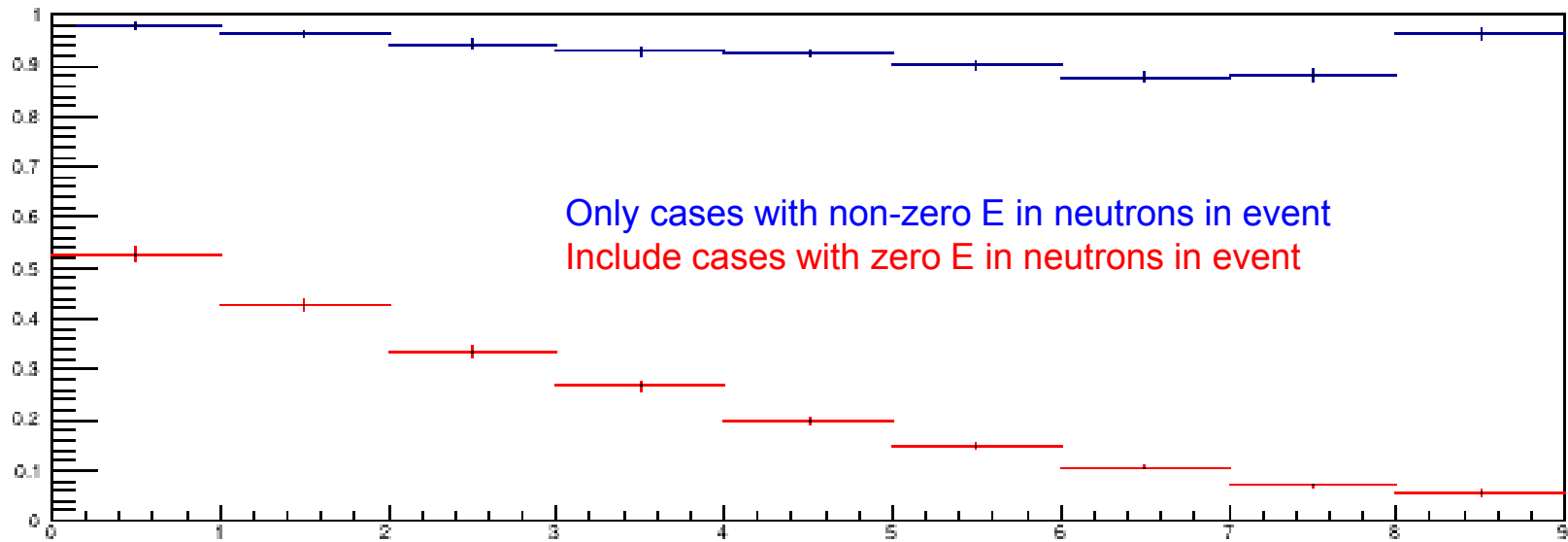
**Note:**

Since each plot has different number of entries, and each bin also has different number of entries, the sum of the parts can be greater than the whole

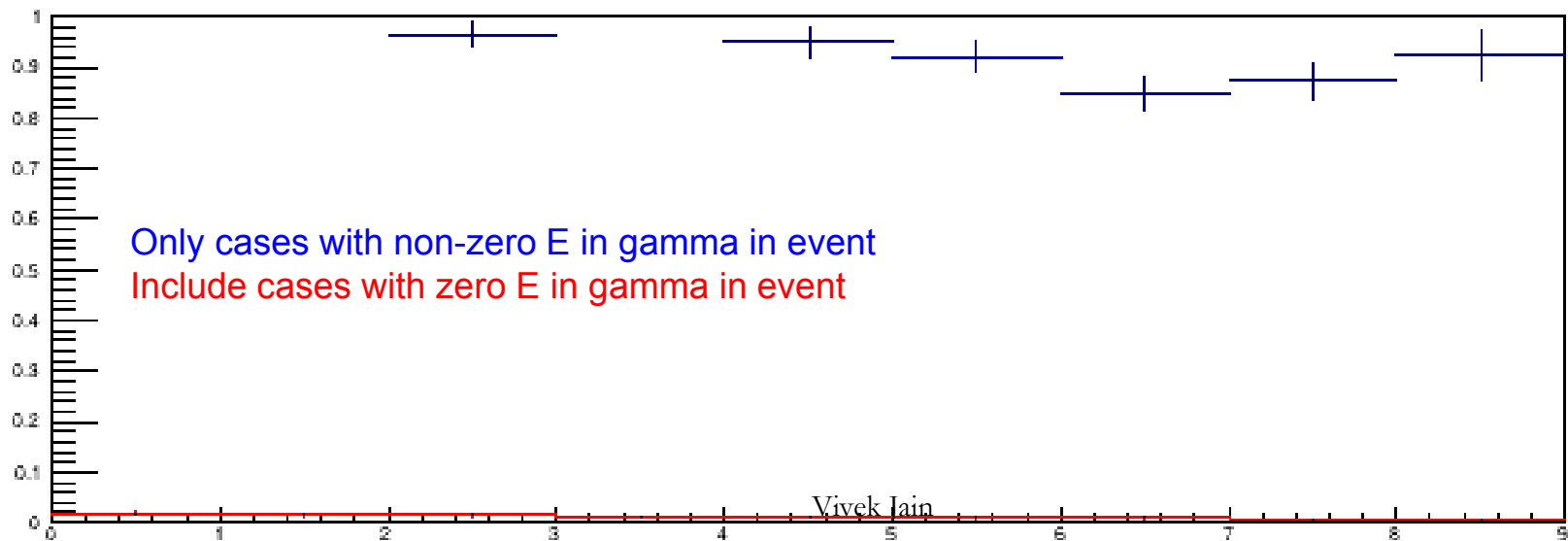


$E_\nu : 1 - 3 \text{ GeV}$

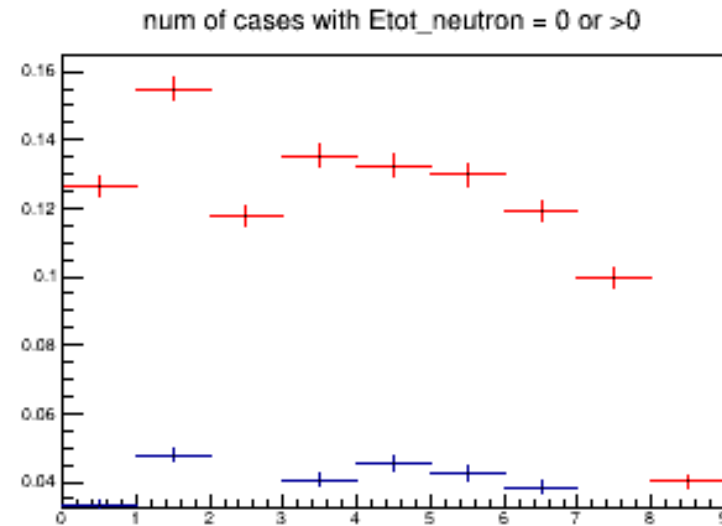
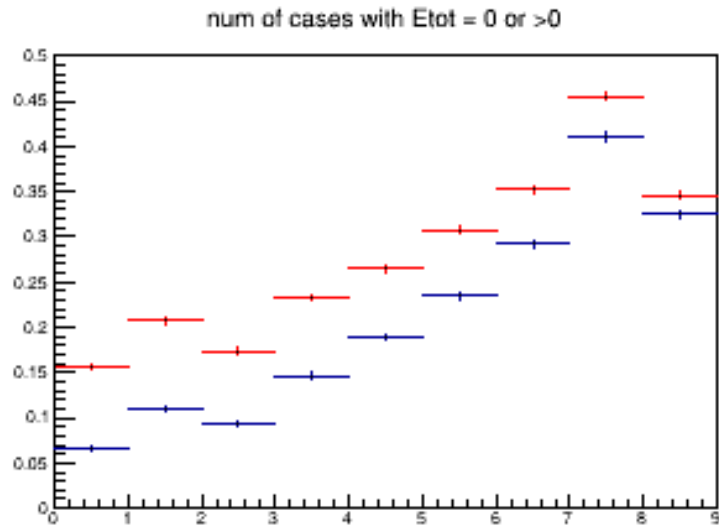
frac E in neutrons in annular rings - only evts w/ non-zero E in neutrons



frac E in gamma in annular rings - only evts w/ non-zero E in gamma



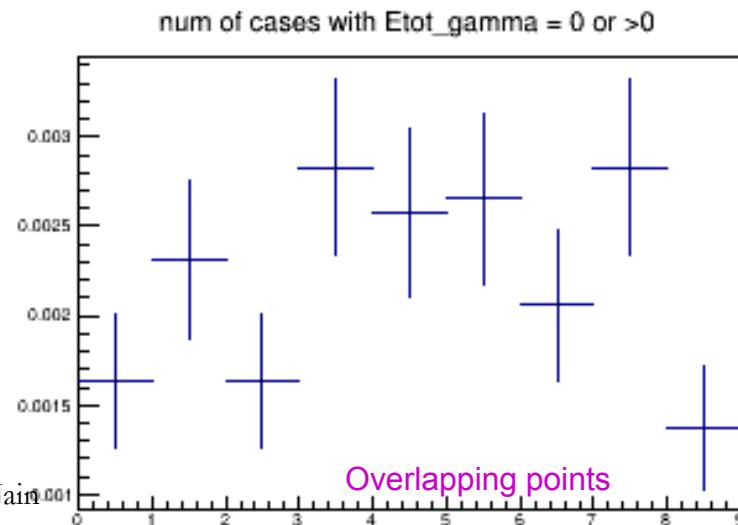
These plots give the fraction of times there is non-zero energy in a ring - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample = 11664 ) Energy in one event can be spread over different rings



Truth, Reco

Incident neutrino E: 3-5 GeV

If a reco. point does not show up, it means it's below the plot's min Y

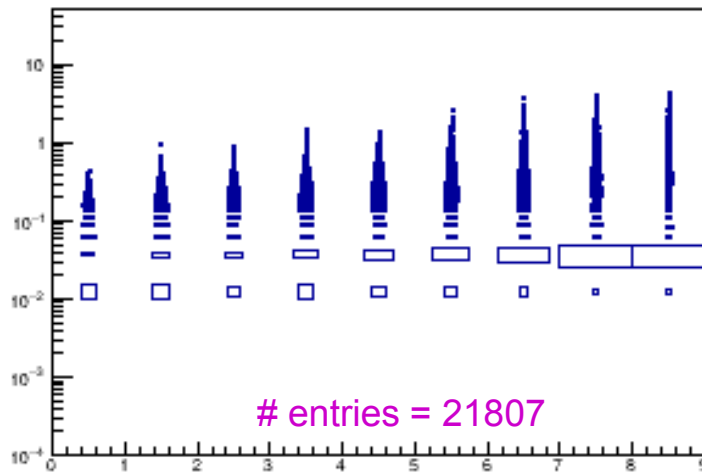


These plots give the amount of non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

Incident neutrino E: 3 - 5 GeV – using reco information

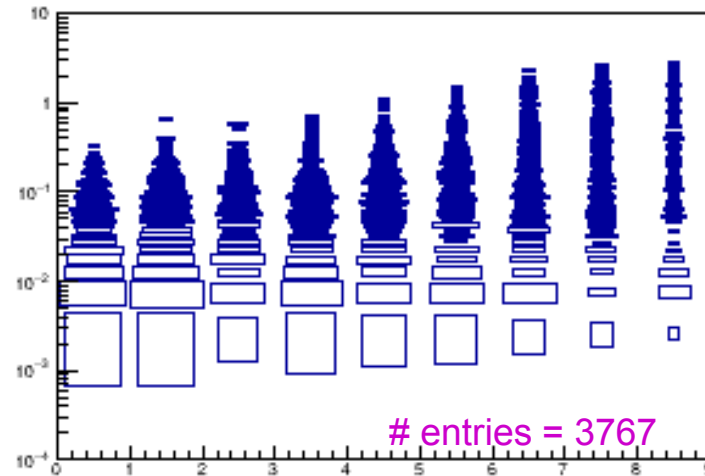
Y-bin width = 5 MeV

reco total energy in annular rings



Y-bin width = 25 MeV

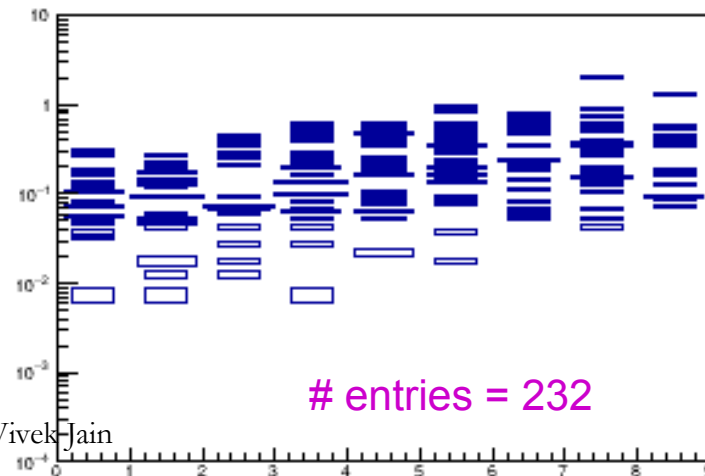
reco total energy in neutrons in annular rings



**Note:**

Each plot has different number of entries, and Each bin has a different number of entries

reco total energy in gamma in annular rings



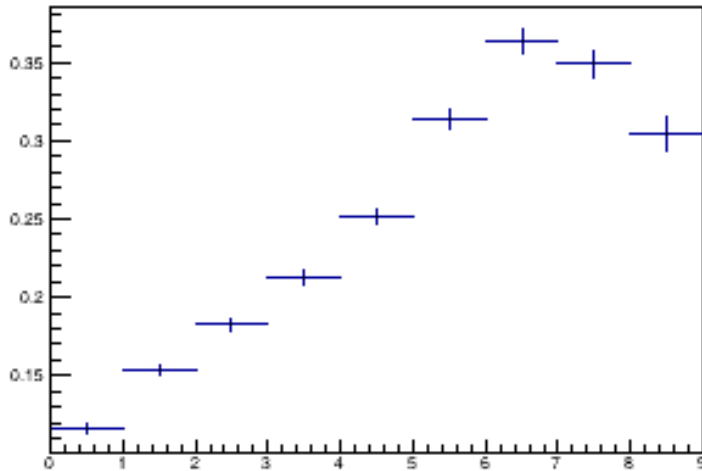
Y-bin width = 5 MeV

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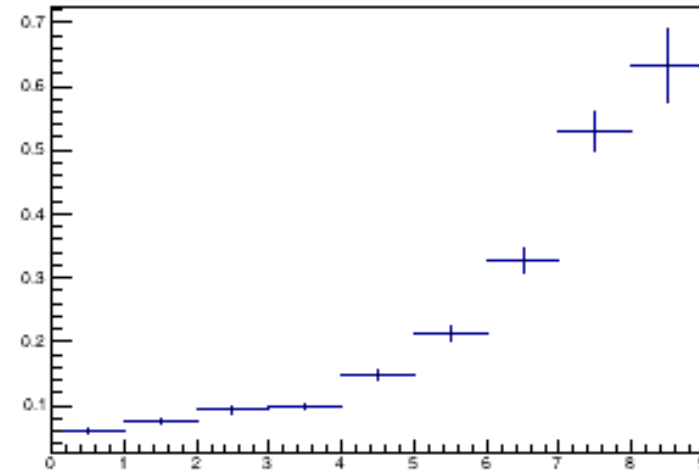
Profile plots give the amount of average non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

### Incident neutrino E: 3 - 5 GeV - using reco information

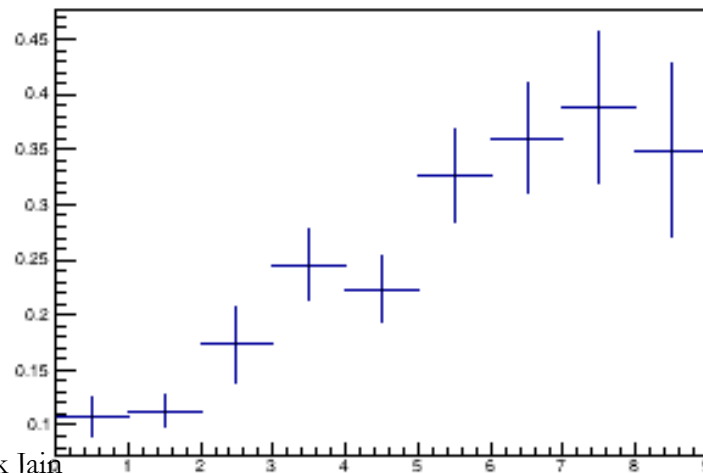
reco total energy in annular rings



reco total energy in neutrons in annular rings



reco total energy in gamma in annular rings

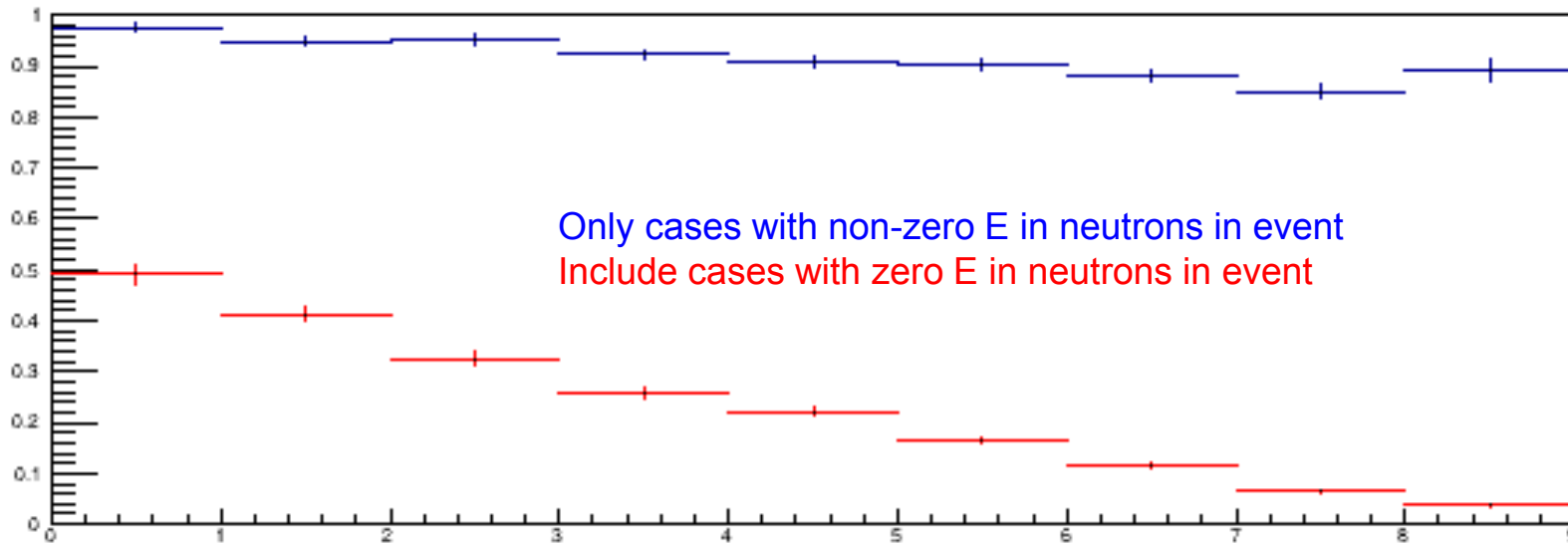


**Note:**

Since each plot has different number of entries, and each bin also has different number of entries, the sum of the parts can be greater than the whole

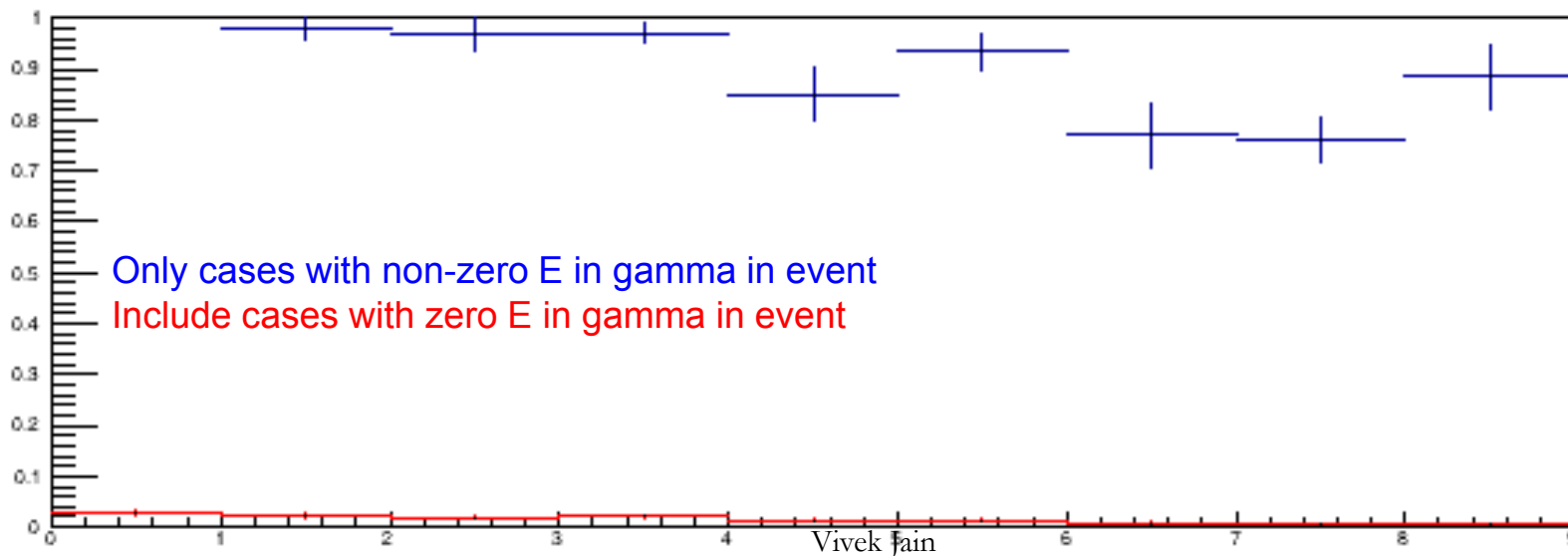
$E_\nu : 3 - 5 \text{ GeV}$

frac E in neutrons in annular rings - only evts w/ non-zero E in neutrons



Only cases with non-zero E in neutrons in event  
Include cases with zero E in neutrons in event

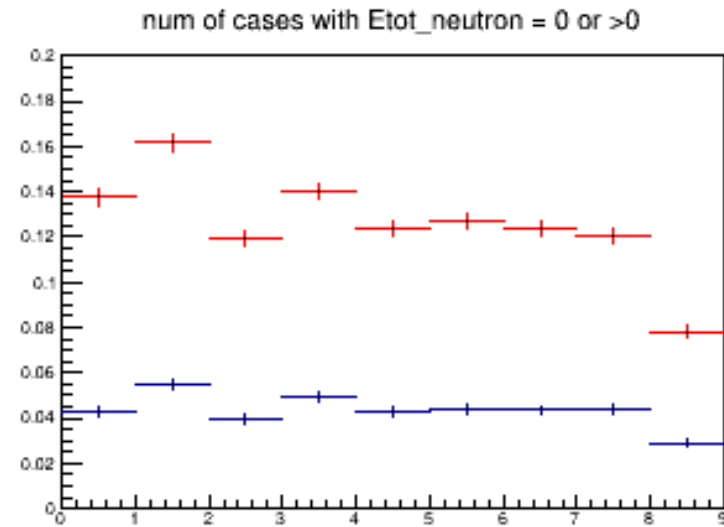
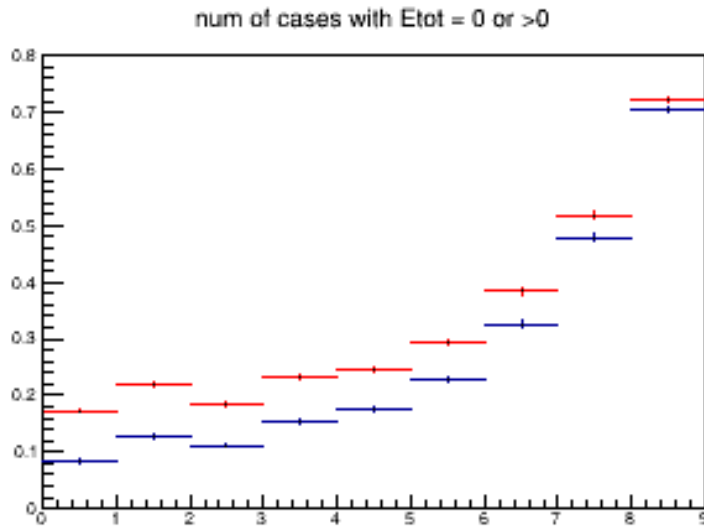
frac E in gamma in annular rings - only evts w/ non-zero E in gamma



Only cases with non-zero E in gamma in event  
Include cases with zero E in gamma in event

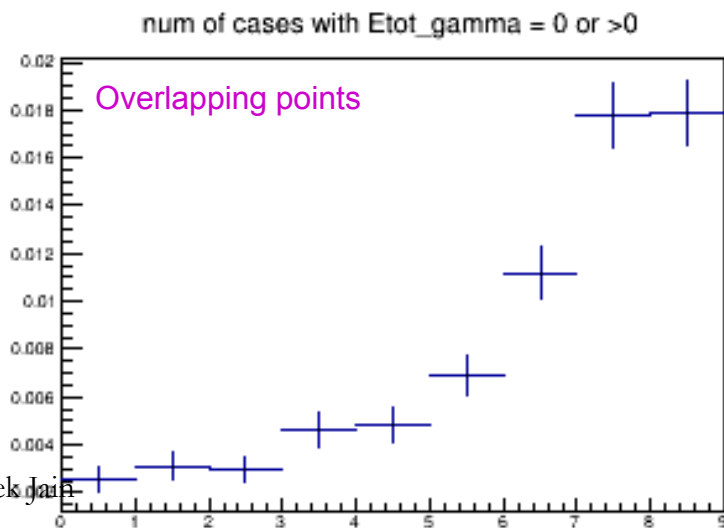


These plots give the fraction of times there is non-zero energy in a ring - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample = 9732 ) Energy in one event can be spread over different rings



Truth, Reco

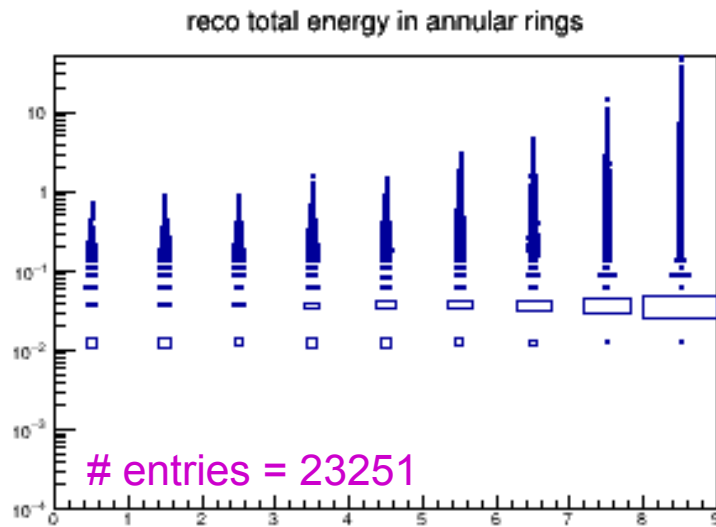
Incident neutrino  $E \geq 5$  GeV



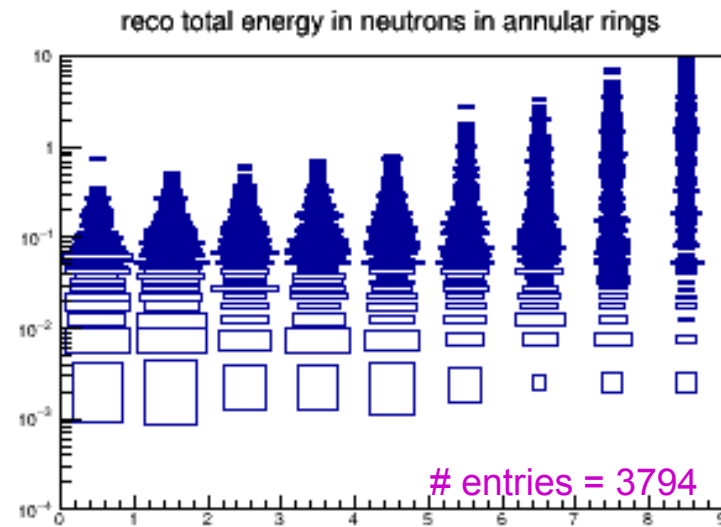
These plots give the amount of non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

Incident neutrino  $E \geq 5$  GeV – using reco information

Y-bin width = 5 MeV



Y-bin width = 25 MeV

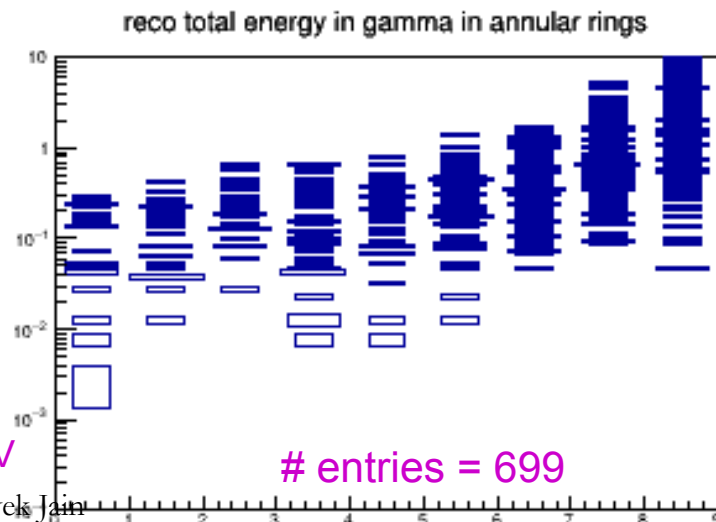


Note:

Each plot has different number of entries, and Each bin has a different number of entries

Y-bin width = 5 MeV

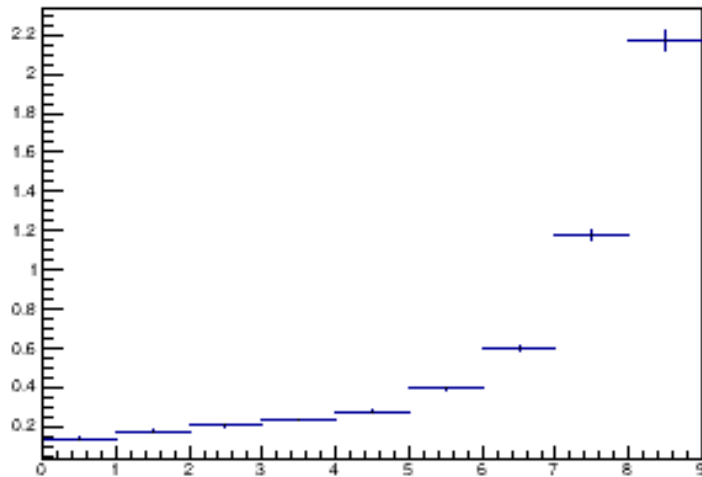
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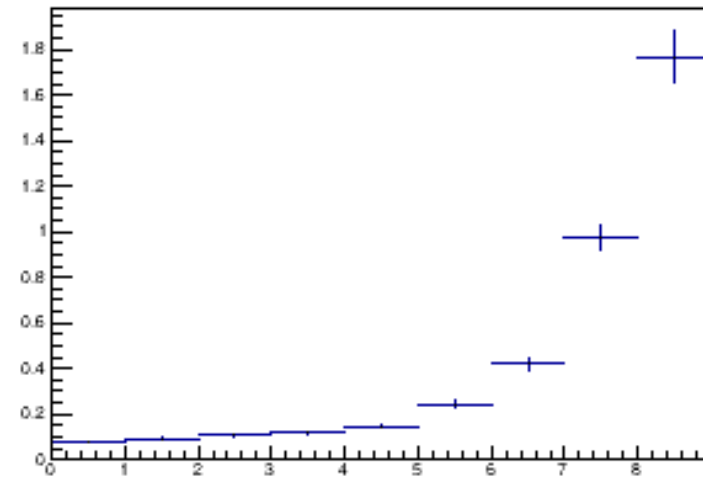
Profile plots give the amount of average non-zero energy in an event in a ring - Energy in one event can be spread over different rings.

### Incident neutrino $E \geq 5$ GeV - using reco information

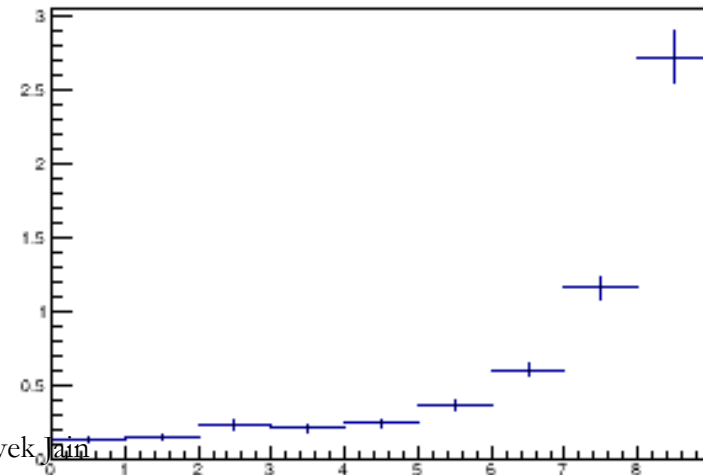
reco total energy in annular rings



reco total energy in neutrons in annular rings



reco total energy in gamma in annular rings

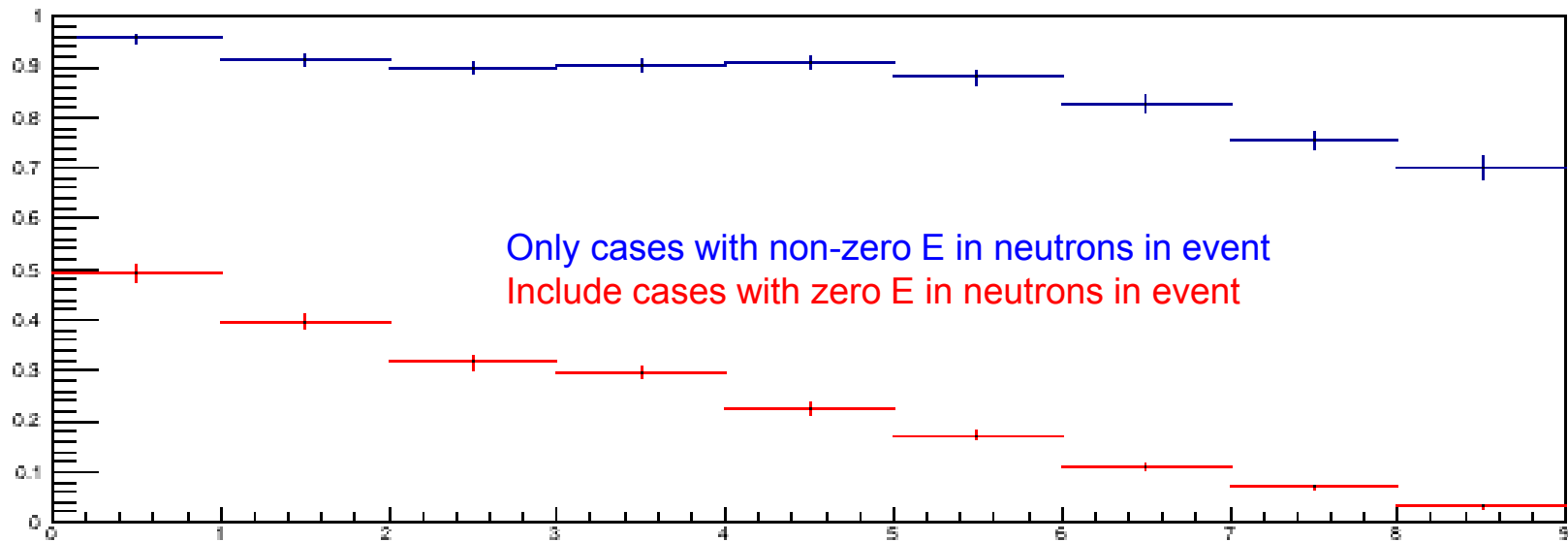


**Note:**

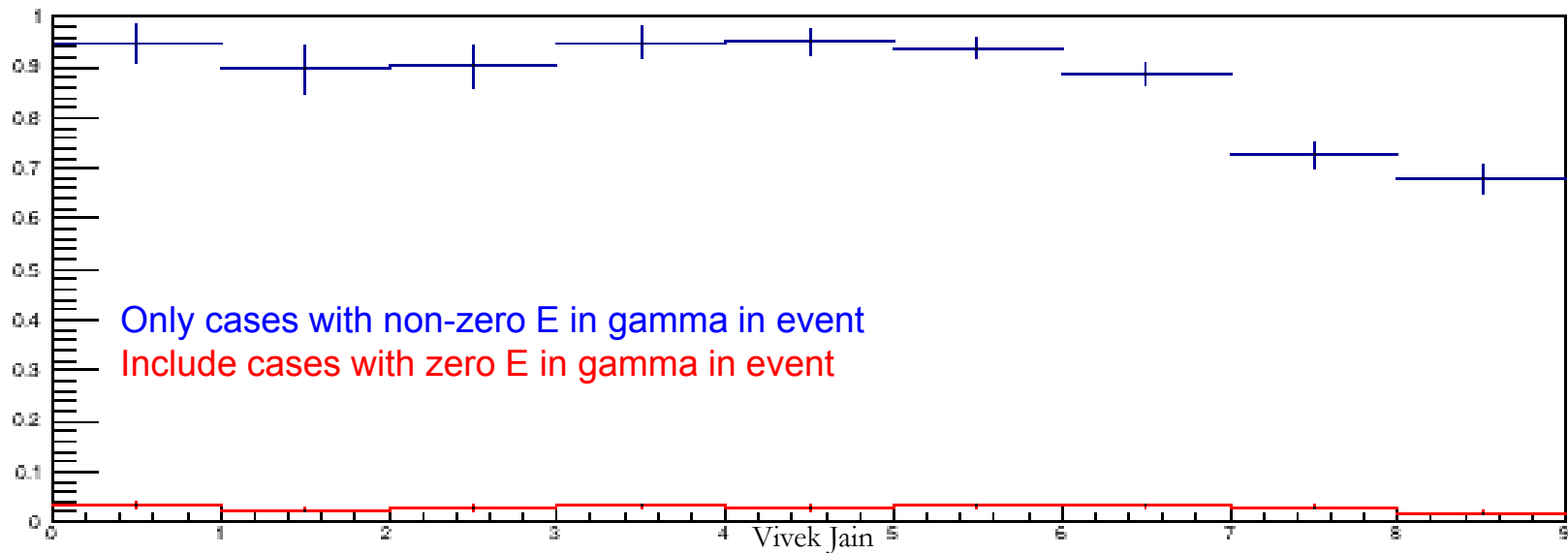
Since each plot has different number of entries, and each bin also has different number of entries, the sum of the parts can be greater than the whole

$E_\nu \geq 5 \text{ GeV}$

frac E in neutrons in annular rings - only evts w/ non-zero E in neutrons



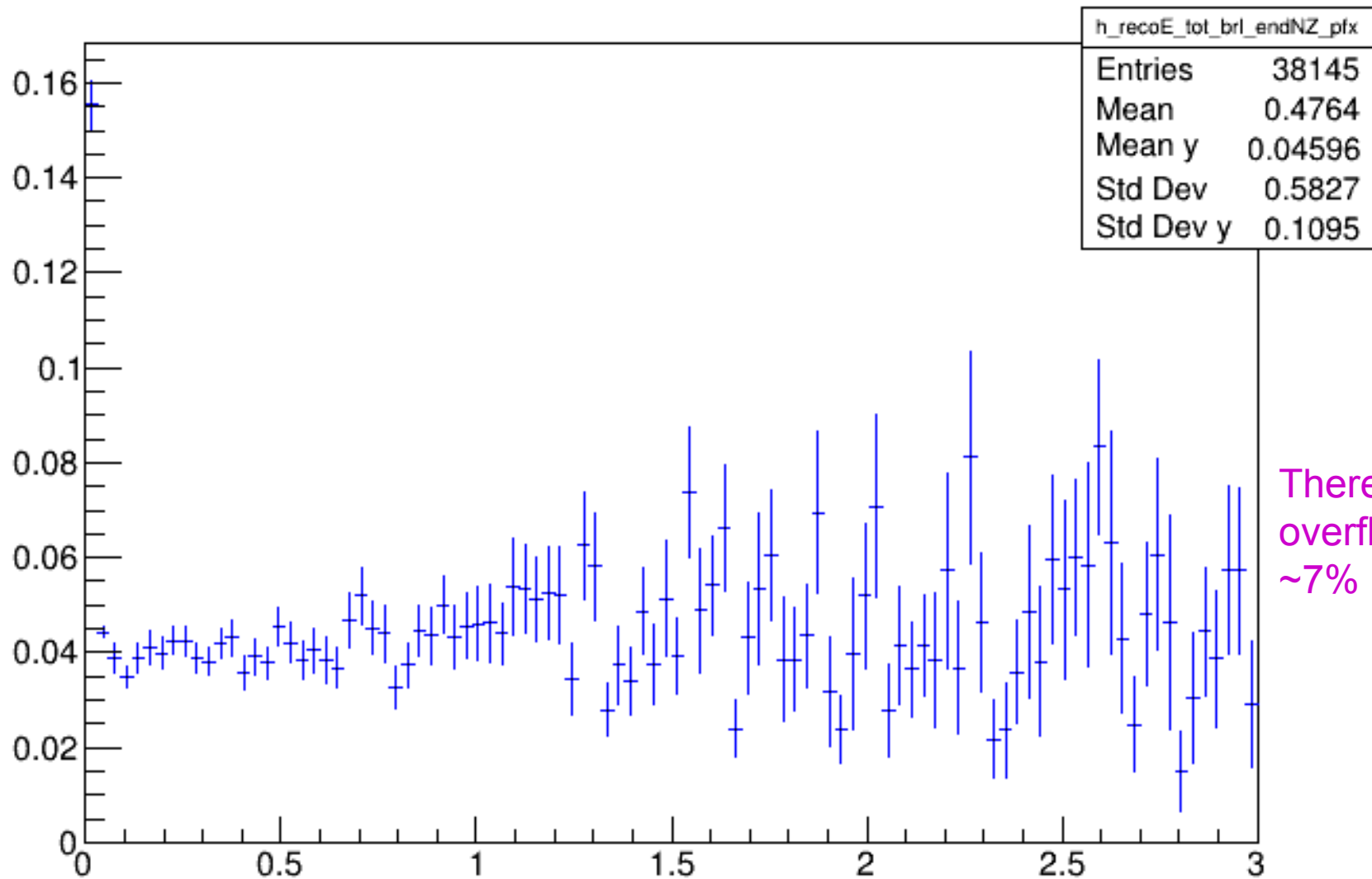
frac E in gamma in annular rings - only evts w/ non-zero E in gamma



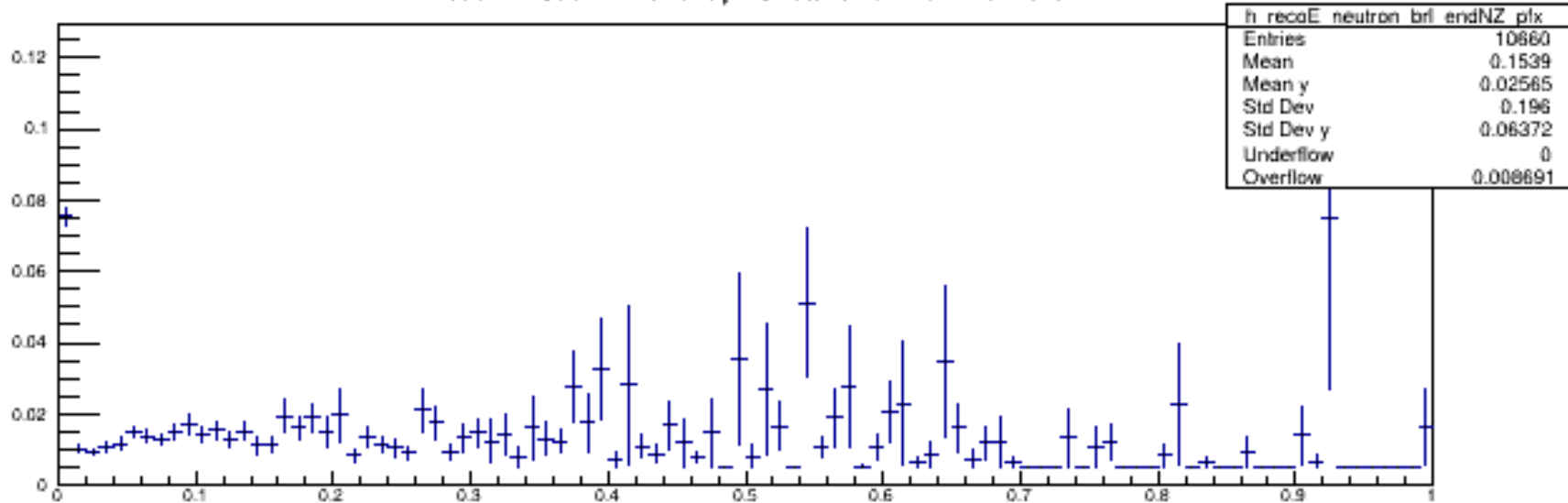
## Now look at energy distribution between barrel and endcap CALO

There has to be some energy in either the barrel or the endcap for this plot to be filled

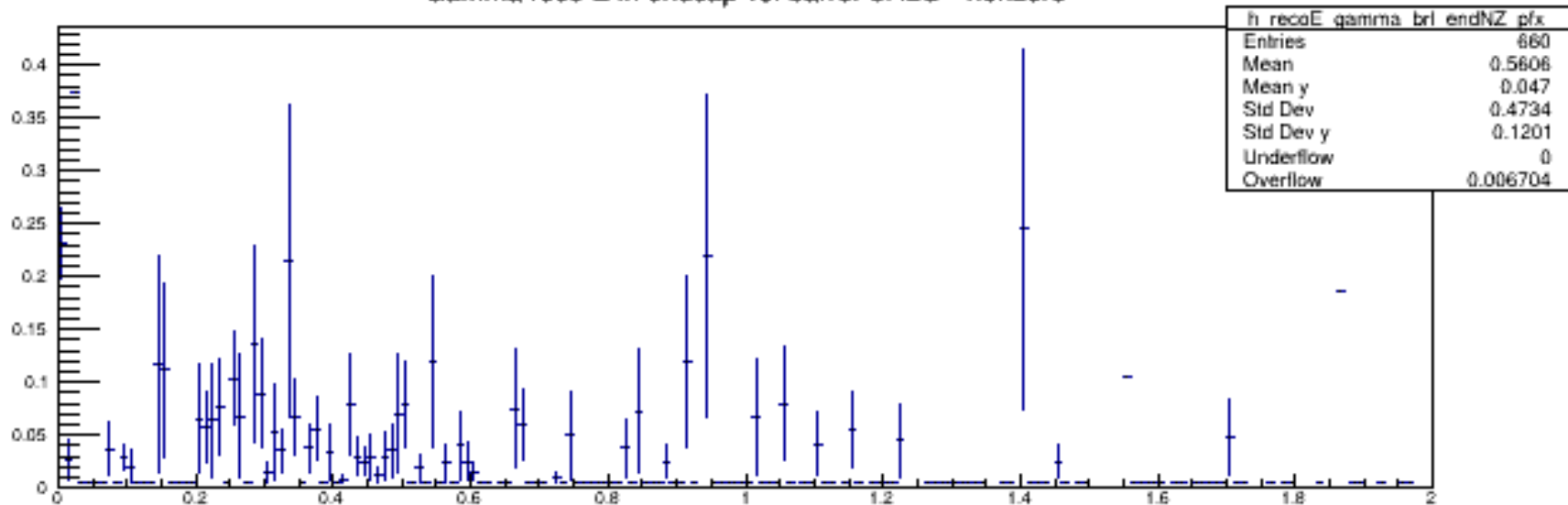
Total reco E in endcap vs. barrel CALO - nonzero case



Neutron reco E in endcap vs. barrel CALO - nonzero



Gamma reco E in endcap vs. barrel CALO - nonzero



There are some overflows ~6% for neutrons, and ~20% for gammas

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Benchmark studies – how does  $\Delta P$  look for various CALO options?

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# Summary

- Work in progress – will incorporate your comments into the next presentation.



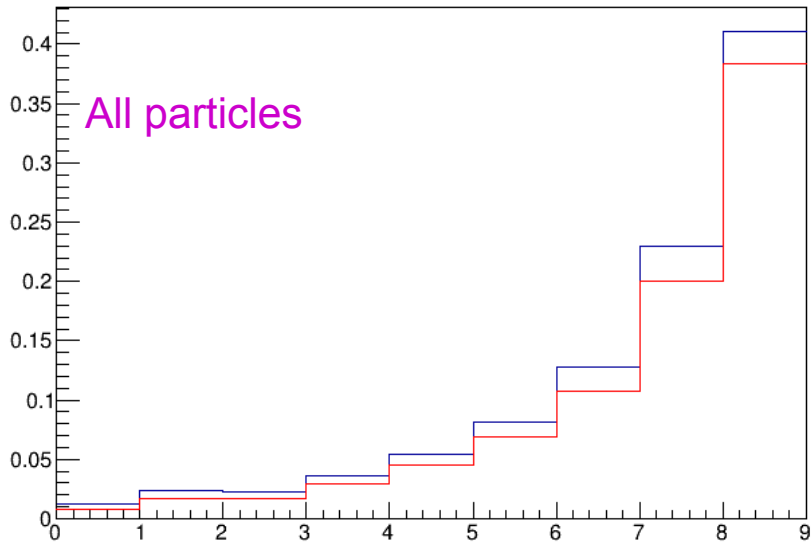
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# Extra Slides

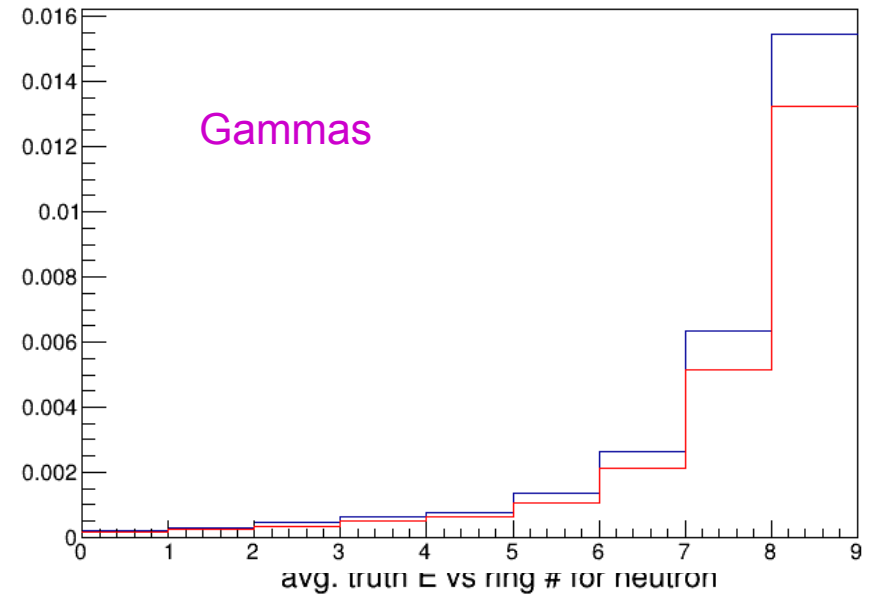
Plots on the following 6 slides are from the previous iteration where I filled  
Them even with E was 0...

These plots give the average E/event in various rings - each bin corresponds to one ring, and the normalization is the same for each bin (= total number of events in sample)  
Energy in one event can be spread over different rings – includes events with 0 energy

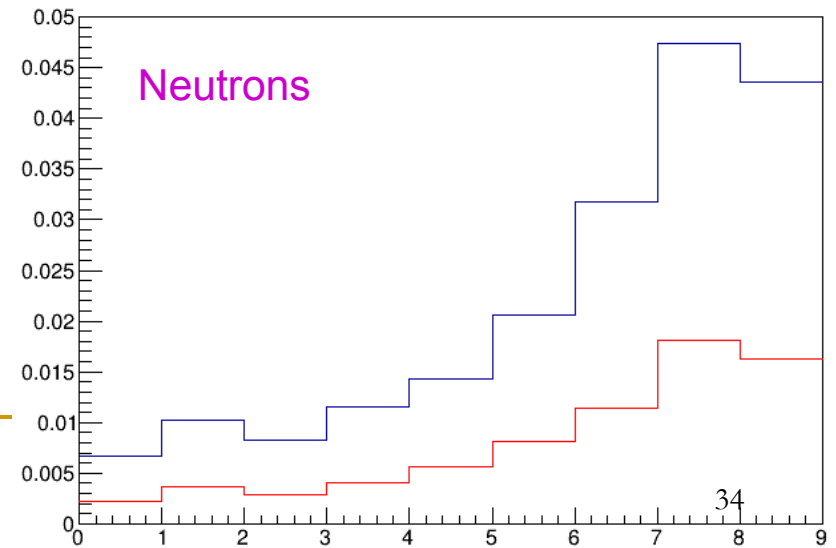
Plots made with both **truth information**, **reco variables**  
 avg. truth E vs ring #



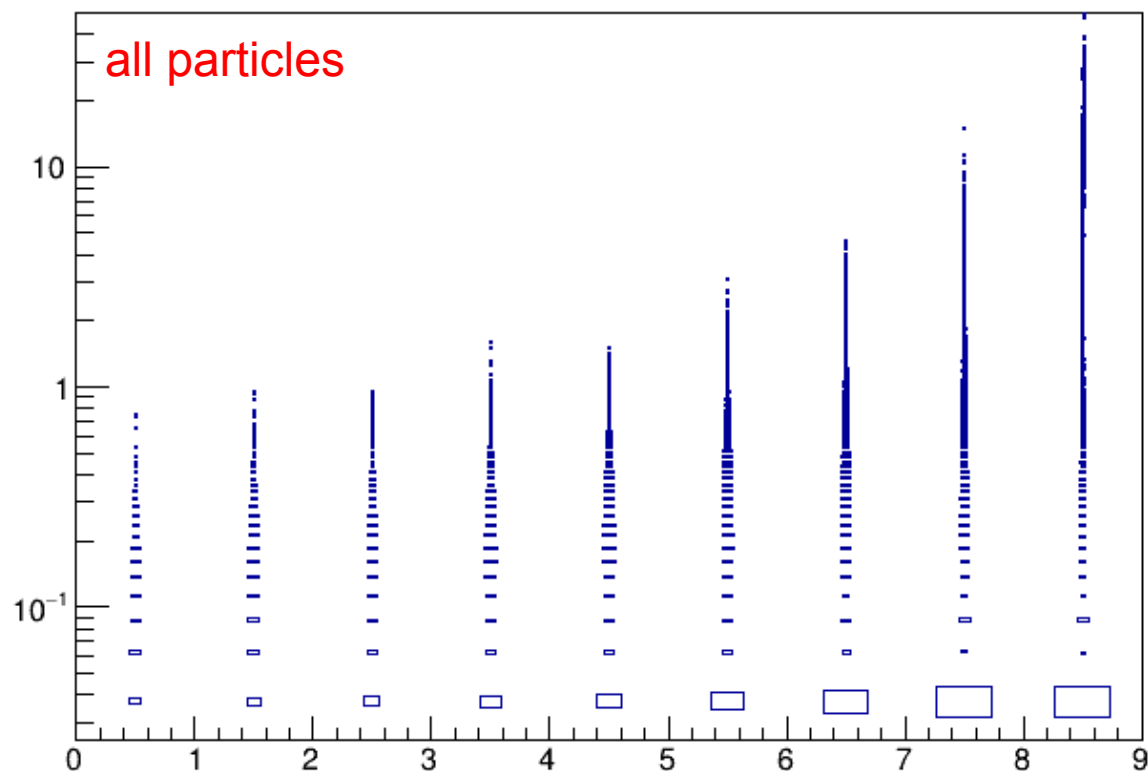
avg. truth E vs ring # for photons



avg. truth E vs ring # for neutron



## reco total energy in annular rings



The energy in each ring in each event is plotted, giving 44295 entries per ring

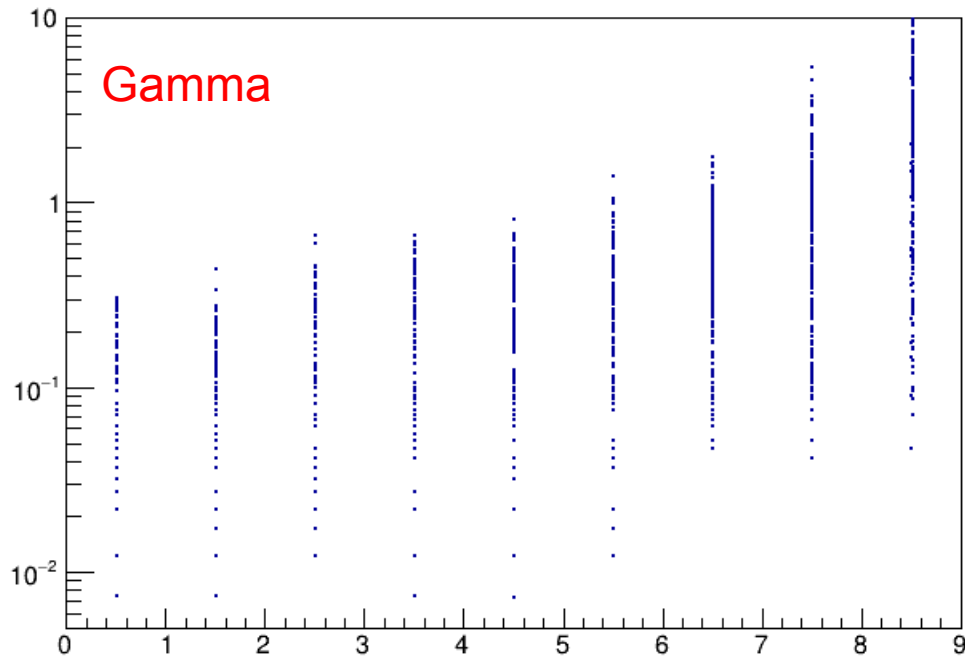
Since this is a log plot, you don't see entries in the first bin that includes  $E=0$

Y-bin width = 25 MeV

# of entries visible in the plot range from 2518 in the first ring to 14585 in the last ring  
The penultimate ring has 16848 entries

# entries in the 2<sup>nd</sup> bin ranges from 351 in first ring to 9098 in the last ring

reco total energy in gamma in annular rings



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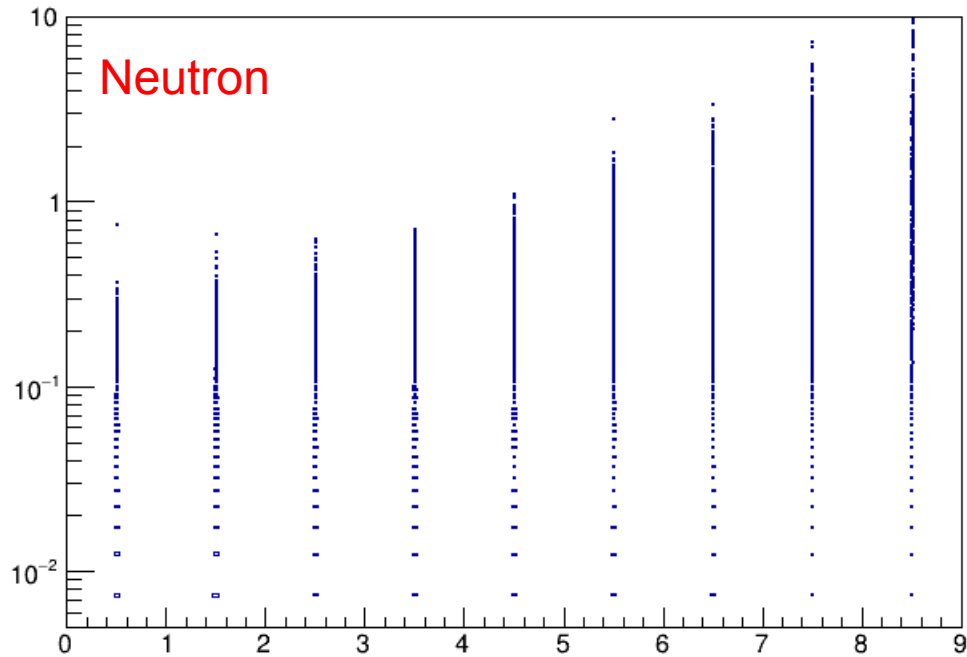
The energy in each ring in each event is plotted, giving 44295 entries per ring

Since this is a log plot, you don't see entries in the first bin that includes  $E=0$

Y-bin width = 5 MeV

# of entries visible in the plot range from 64 in the first ring to 208 in the last ring  
The penultimate ring has 242 entries

## reco total energy in neutrons in annular rings



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The energy in each ring in each event is plotted, giving 44295 entries per ring

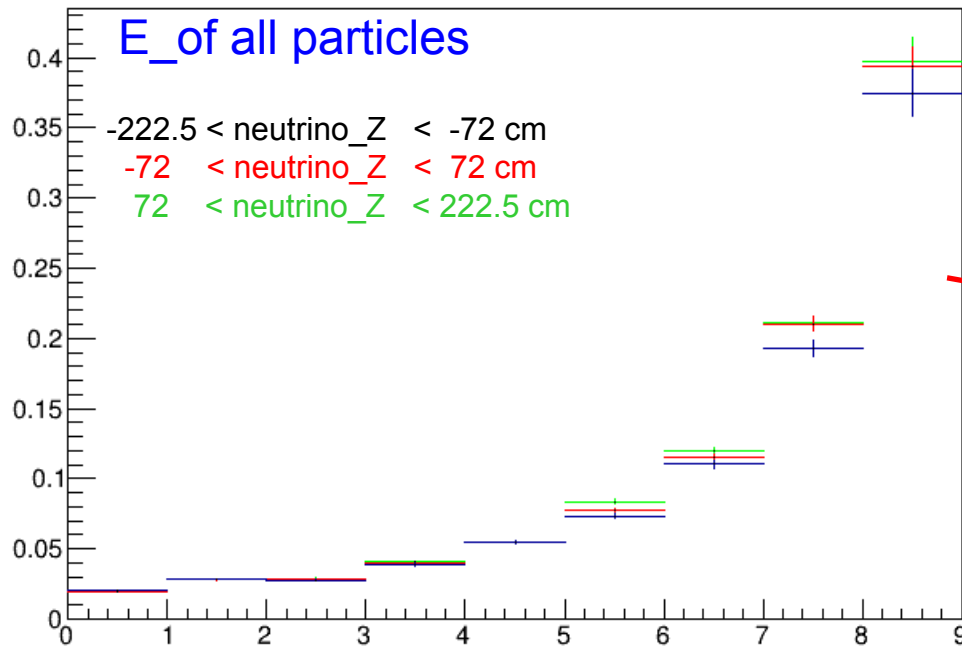
Since this is a log plot, you don't see entries in the first bin that includes  $E=0$

Y-bin width = 5 MeV

# of entries visible in the plot range as a function of ring number are:

1484, 2094, 1457, 1803, 1847, 1756, 1641, 1356, 651

total reco energy in annular rings:



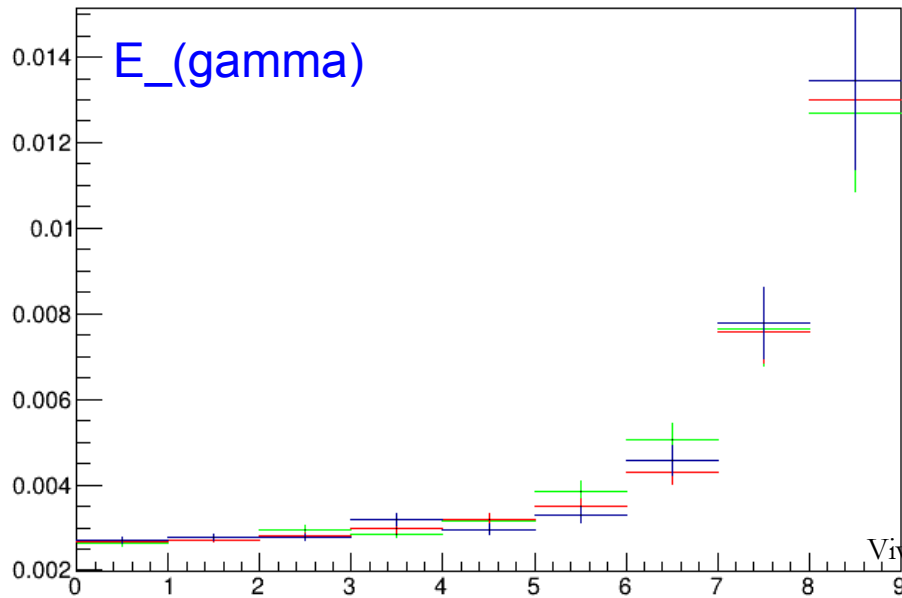
Profile plots

X-axis: ring #

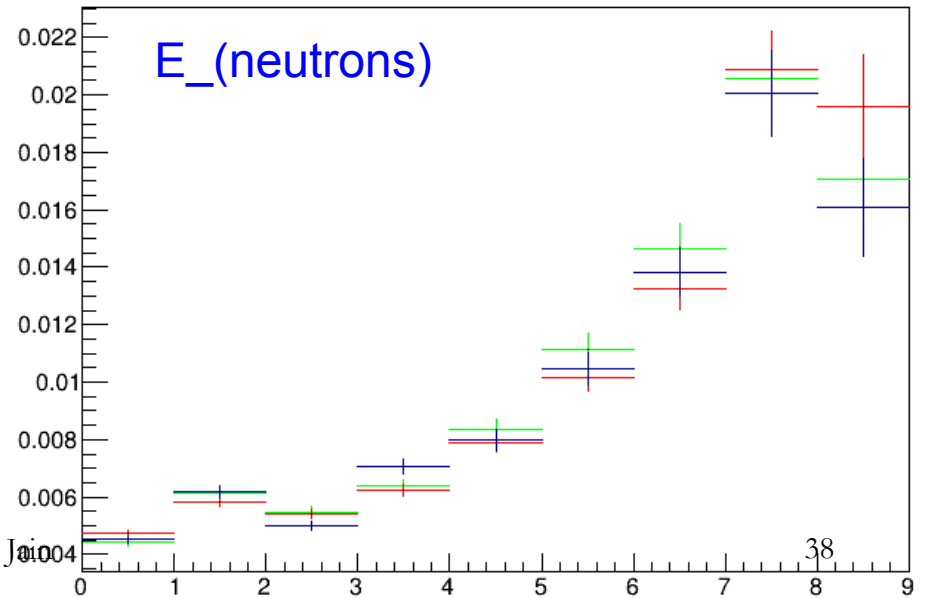
Y-axis: ave. E/event in ring

Mild dependence on neutrino Z-vertex position

total reco energy in gammas in annular rings:



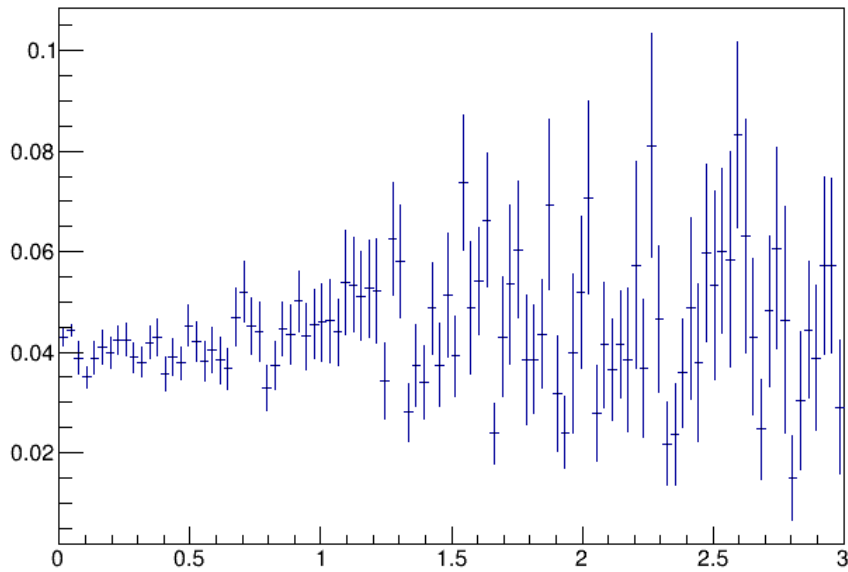
total reco energy in neutrons in annular rings:



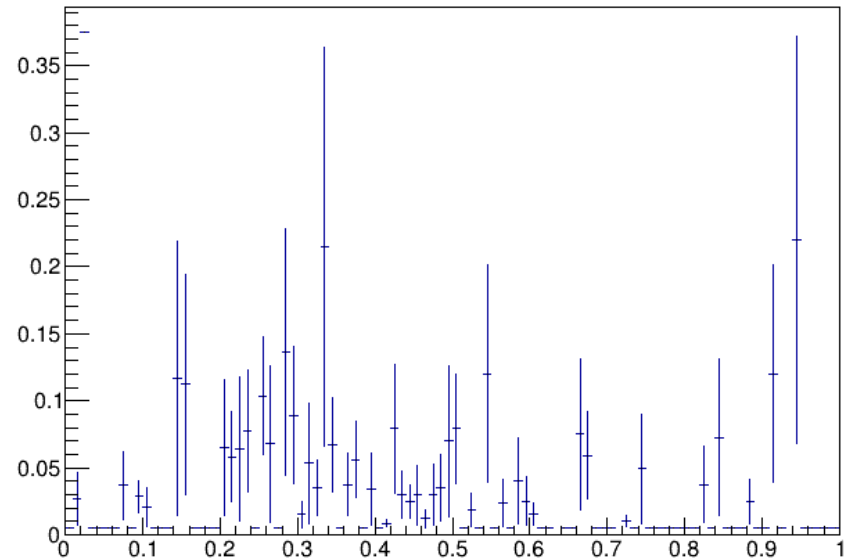
Now look at E in barrel vs. E in endcap for a given event – aggregate over all events

X-axis: Total E in event in barrel, Y-axis: Total E in event in endcap

Total reco E in endcap vs. barrel CALO



Gamma reco E in endcap vs. barrel CALO



Neutron reco E in endcap vs. barrel CALO

